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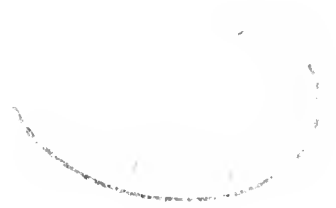

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Art. I.—The Tertiary Geology of Australia.

By F. A. SINGLETON, D.Sc.

[Read 9th November, 1939; issued separately 1st February, 1941.]

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Introduction.

At a symposium on Tertiary Formations of the Pacific Region at the First Pan-Pacific Scientific Conference (Honolulu, 1920), an account of the Post-Cretaceous Rocks of Australia was given by Richards (15). At the Second Congress (Australia, 1923), Chapman and Singleton (27) contributed a more detailed paper on the Tertiary Deposits of Australia, a supplementary note to which was furnished to the Fourth Congress (Java, 1929) by the author (43).

In the past decade not only have undoubted Eocene deposits been identified in Australia, but also considerable changes have taken place in the views of the joint authors above-mentioned, and their account no longer represents the views of either of them. Consequently the time seems ripe to offer an account of the present state of our knowledge of the Tertiary Geology of the Commonwealth of Australia, including Tasmania but not New Guinea.

The present paper seeks to cover a wider field than either of the preceding accounts, necessarily in outline only, so that for details the papers listed in the bibliography should be consulted.

Geographic Distribution.

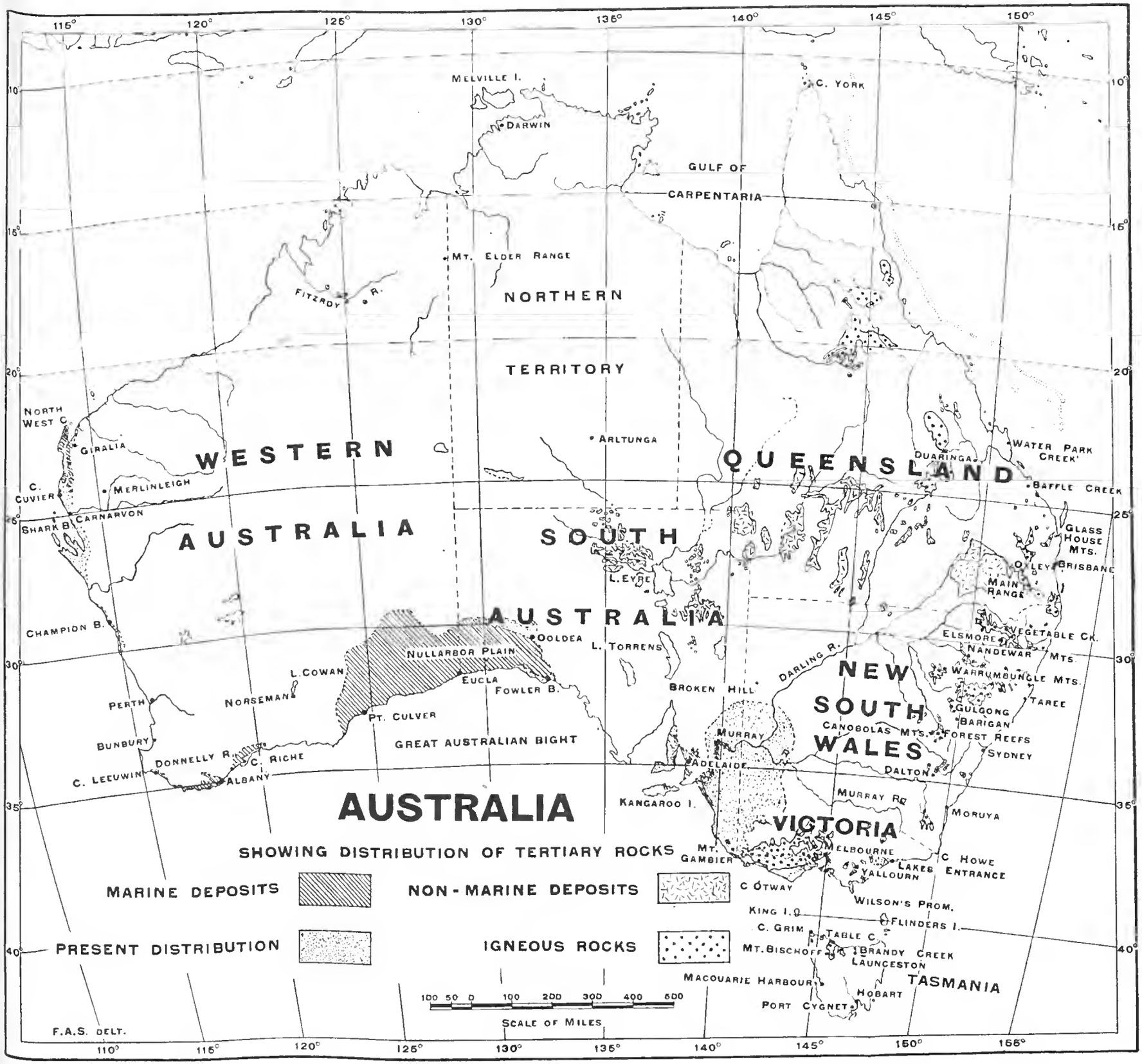
Of the three million square miles, in round figures, of the continent of Australia, marine Tertiary formations occupy about $6\frac{1}{4}$ per cent., of which outcrops are subordinate to areas in which they are covered by later deposits or by igneous rocks.

They form a discontinuous fringe from lat. 21° 46′ S., long. 114° 6′ E. at North-West Cape in West Australia, along the western and southern coasts of the continent to lat. 37° 50′ S., long. 148° 5′ E. near Lakes Entrance in Victoria, with small areas on the north-west coast of the island of Tasmania and on the islands of Bass Straits. While their occurrence is chiefly along a coastline of about 5,000 miles, they are found inland for 250 miles in the basin of the Murray River, where they extend into New South Wales, and perhaps nearly as far in the little-known region north of the Great Australian Bight. Over this vast area, extending nearly 1,350 miles north to south and 1,750 miles east to west, virtually nothing but reconnaissance work has been done except in the more populous areas of the south-east, in the States of South Australia, Victoria, and Tasmania, where the studies of a limited band of workers over the past three-quarters of a century have accumulated a considerable literature, both stratigraphical and palaeontological.

Non-marine deposits are more widespread, notably in the interior of the continent, but can seldom be satisfactorily dated except in the south-east, where they come into relation with marine deposits or with igneous rocks whose age is otherwise determinable. Elsewhere, particularly when unfossiliferous, it is seldom possible to subdivide them or even to distinguish them from post-Tertiary deposits.

Igneous rocks are more particularly developed in Eastern Australia from Queensland to Tasmania, but again it is difficult to draw the boundary between Tertiary and Quaternary igneous activity, and it has not always been possible to do so on the map. More precise definition of age, by interrelation with marine deposits, is practically confined to Victoria, and in the other States physiographic evidence must be relied upon.

It will be seen that even the areal distribution of the Tertiary rocks is but imperfectly known, and it follows that the boundaries shown on the map must necessarily be accepted as tentative, as must, indeed, be regarded much of the account which follows.



MAP 1.

Geological Map of Australia and Tasmania, showing distribution of Tertiary Rocks. Modified from geological map of the Commonwealth (2) and State geological maps

Classifications of the Marine Deposits.

The Tertiary controversy in Australia has undergone such kaleidoscopic changes and is so far, even now, from finality that it is difficult for one unfamiliar with its detailed history to understand the literature. Consequently it seems desirable, before outlining the present views of the writer, to give a brief historical account to supplement those given by Pritchard (12), for the period prior to 1895, and by Richards (15) up to 1921.

Views of McCoy and the Victorian Geological Survey.

Although Professor (afterwards Sir Frederick) McCoy never expressed his views in the form of a correlation table, yet it is possible from publications to infer them and those of the Geological Survey of which he was the palaeontologist, and to translate them into the local nomenclature established since his lifetime.

In 1861 McCoy (280, p. 168) referred the beds between Mount Martha and Mount Eliza [Balcombe Bay = type Balcombian] to the Upper Eocene, but five years later (281, p. 323) adopted for them the newly introduced term Oligocene, while he regarded the greater part of the Victorian Tertiaries as Lower Miocene. Subsequently he always combated the prevailing contemporary view of an Eocene age, remarking in 1894 (168, p. 48) that the Muddy Creek and Schnapper Point [Balcombe Bay] beds were "of newer date than any true Eocene Tertiary type, such as the London clay."

From papers published between 1874 and 1882 (282-288) one can set out McCoy's views on correlation as follows:—

Oligocene: Near Mount Martha [Balcombe Bay = type Balcombian]; near Mount Eliza [Grice's Creek]; Moolap, Ad. 14 [Curlewis; later, as Outer Geelong Harbour, Ad. 12, to Miocene]; Fyansford. As Oligocene or Upper Eocene: 2 miles NW. of Cape Otway. As Lower Oligocene: coast between Aire River and Castle Cove; Princetown, 3 miles W. of Gellibrand River. As Upper Oligocene: Shelford.

Miocene: Bird Rock Point, ¾ mile W. of Spring Creek [Torquay = type Janjukian, as Lower, Middle, and Upper Miocene]; Waurn Ponds; Corio Bay; Boggy Creek, near Sale; Mitchell River, Bairnsdale. As Middle Miocene: coast 1 mile W. of Sherbrook River. As Upper Miocene: Muddy Creek [upper beds]; Moorabool River, near Maude [upper beds].

Pliocene: By implication, Jemmy's Point, Gippsland Lakes [Kalimna = type Kalimnan]. As Lower Pliocene: Mordialloc [Beaumaris, upper beds = type Cheltenhamian]; Flemington [Royal Park, lower beds].

It will be seen that McCoy would have regarded the Balcombian as antecedent to the Janjukian, but that he included with the former the Cape Otway and Aire Coastal sections, which others have referred to the Janjukian. He would also have regarded the

upper beds of Muddy Creek as pre-Kalimnan and the lower beds at Flemington as post-Barwonian, neither view being accepted by any subsequent author.

McCoy's views were essentially those of the Geological Survey of Victoria, as summarized in 1887 by Murray (9), who recognized three principal groups—Lower Tertiary (Oligocene), Middle Tertiary (Miocene), and Upper Tertiary (Pliocene), and given more fully by Pritchard (12, pp. 358-9).

Views of Tate and Dennant.

In 1878, soon after his arrival in South Australia, Professor Tate (171) divided the marine beds at Aldinga into two series, later (47) called Eocene and Miocene, and those of the River Murray cliffs into three series, of which the upper was placed on the same horizon as Hallett's Cove and the upper Aldinga beds in South Australia and the Muddy Creek beds in Victoria. The lower Aldinga beds, though equivalent in part to the middle and lower Murray series, were considered on the whole inferior to them. These views were set out in tabular form (47, p. liii) in the following year.

In 1885 Tate (175), having restricted his upper Murravian series to the oyster beds, correlated instead the middle Murravian with the Muddy Creek beds, which in 1889 Dennant (83) showed to be divisible into two series. The lower, regarded as low in the Eocene, Dennant placed with the beds of Mornington [Balcombe Bay]; the upper, believed not older than Miocene, with those of Mordialloc [Beaumaris]. As next younger than these latter, and probably early Pliocene, Dennant regarded the Ostrea limestone of the upper part of the cliffs at Portland Bay and the Glenelg River.

In the following year he discussed further (84) supposedly still younger beds on the Glenelg River, originally described by him in 1887 (82), under the name of Bankivia beds, as Pleistocene. These constitute the type beds of the Werrikooian.

Meanwhile Tate (177) had announced the discovery, by borings in the Adelaide plains [type Adelaidean], of marine Pliocene in South Australia, and had discussed (178) the Tertiary stratigraphy of the Adelaide area.

Still later Dennant (85) correlated with the upper beds at Muddy Creek, as Miocene, the strata at Jemmy's Point [type Kalimnan], and with the Eocene those of the Mitchell River near Bairnsdale. These two deposits were subsequently described in greater detail by Dennant and Clark (90, 91).

During the period 1893-6 Tate and Dennant, in a series of papers (183-185), discussed in detail the correlation of the marine Tertiaries of Australia, a summary of which had been given by Tate (49). These authors referred all the marine deposits classed as Oligocene and as Miocene by the Geological Survey of

Victoria, to the Eocene, in which they noted, however, two faunal types. One, the Aldinga-facies, which probably indicates a relatively low position in the Eocene, is represented in the deeper beds of the Adelaide bores and in Victoria at Cape Otway. The other, best known at Muddy Creek, is conspicuous in most Victorian sections, such as the Gellibrand River, Camperdown, Shelford, and the Geelong district, including Western Beach [Corio Bay], Lower Moorabool [Batesford-Fyansford] and Curlewis-Belmont, as well as the Murray River and Mount Gambier district in South Australia; probably also Schnapper Point [type Balcombian] and Bairnsdale. As to Spring Creek [type Janjukian] and Table Cape (Tasmania), the authors reserved their opinion, but considered at Birregurra there is a mingling of the two faunas.

The views of Tate and Dennant may be condensed as follows:—

Eocene: In South Australia: Wilson Bluff to Head of Great Australian Bight; Point Turton, Edithburg, Surveyor's Point, etc., on Yorke Peninsula; lower beds in Adelaide bores and at Aldinga; Kingscote on Kangaroo I.; River Murray Plain; Mount Gambier District.

In Victoria: Muddy Creek (lower beds); Portland, Glenelg River, and Apsley; Warrnambool; Camperdown; Port Campbell, Sherbrook River, and Gellibrand; Aire River and Cape Otway; Spring Creek [type Janjukian]; Birregurra; Shelford: Maude (lower beds); Moorabool and Barwon Rivers, Geelong district: Schnapper Point [Balcombe Bay; type Balcombian]; Cheltenham [Beaumaris; type Cheltenhamian]; Mitchell River, Bairnsdale.

In Tasmania: Table Cape.

Miocene: In South Australia: River Murray Cliffs (oyster-beds or Upper Murravian series); Adelaide; Aldinga Bay and Hallett's Cove.

In Victoria: Portland and Glenelg River (Ostrea-limestone); Muddy Creek (upper beds); Jemmy's Point [type Kalimnan].

Older Pliocene: Marine sands beneath mammaliferous drift of Adelaide Plain [type Adelaidean], South Australia.

Newer Pliocene: Glenelg River at Limestone Creek, Victoria [type Werrikooian]. These were later regarded as Lower Pleistocene by Tate.

Subsequently Tate, in one of his last papers (181), modified his views, notably as regards the Spring Creek beds, as follows:—

Post-Eocene (*? Oligocene*): Beaumaris (Cheltenham), Murray Desert, Table Cape, and Spring Creek [type Janjukian].

Upper Eocene: Muddy Creek, Gippsland Rivers, River Murray, around Port Phillip [includes type Balcombian], Gellibrand River, and upper part of Lower Aldingian Series.

Middle Eocene: Cape Otway and middle section of Lower Aldingian.

Lower Eocene: Chalk of the Great Australian Bight, lower part of Lower Aldingian Series, and Croydon Bore.

It is noteworthy that, like McCoy, Tate would have placed the Balcombian below the Janjukian, thus reversing Hall and Pritchard's sequence, yet he agreed with the latter authors in placing the Cape Otway and part of the lower Aldinga beds (included in the Janjukian by Hall and Pritchard) below those of Muddy Creek and Balcombe Bay.

Finally, in 1903, Dennant and Kitson (275), in a faunal catalogue, utilized the following:—

Eocene to Oligocene:

Group A (including Lower and Middle Eocene of Tate): Aldinga, Adelaide Bore, etc., in S. Australia. Brown's Creek, Cape Otway, Aire Coast, etc., in Victoria.

Group B (Upper Eocene of Tate): Murray River and Mt. Gambier in S. Australia. Glenelg River, Muddy Creek [lower beds], Gellibrand River, Camperdown, Birregurra, Shelford, Lower Moorabool [Fyansford, etc.], Corio Bay, Mornington [Balcombe Bay, type Balcombian], Flinders and Mitchell River, in Victoria. Tentatively included are the Victorian localities of Fishing [=Fisher's or Fischer's] Point on the Aire River, Waurn Ponds, and Maude.

Group C (Tate's post-Eocene, on which Dennant and Kitson express no opinion): Spring Creek [type Janjukian], Victoria. Table Cape, Tasmania.

Group D (provisionally Oligocene): Murray Desert in S. Australia. Keilor, South Yarra, Royal Park, and Beaumaris [type Cheltenhamian] in Victoria, the presence of two series at the two last mentioned localities being regarded as unestablished.

Miocene: Hallett's Cove, upper beds at Edithburg, Adelaide, Aldinga and Murray Cliffs in South Australia. Horsham; upper beds at Glenelg River, Muddy Creek, Shelford and Bairnsdale; Gippsland Lakes [Kalimna, type Kalimnan, etc.].

Older Pliocene: Dry Creek and Croydon Bores, near Adelaide, S. Australia [Adelaidean].

Newer Pliocene: Limestone Creek [type Werrikooian]. Glenelg River; Moorabool Viaduct, Victoria.

Views of Hall and Pritchard.

Tate's view as to the Eocene age of the Older Tertiary deposits was supported by Hall and Pritchard, who in 1895 (106) proposed their subdivision in Victoria, from above downwards, as follows:—

(1) *Clays of the Lower Muddy Creek Type.*—Muddy Creek, Gellibrand, Camperdown, Birregurra, Shelford, Murgheboluc, Southern Moorabool Valley (Fyansford, etc.), Belmont, Lake Connewarre (Campbell's Point), Curlewis, Corio Bay, Altona Bay (bore), Newport (shaft), Mornington [Balcombe Bay], Bairnsdale (Mitchell River).

(2) *Polyzoal Limestone of the Waurn Ponds Type.*—Waurn Ponds, Batesford, Maude [upper beds], Curlewis, Flinders, and perhaps at Airey's Inlet and Muddy Creek.

(3) *Clays and Limestones of the Spring Creek Type.*—Spring Creek, Maude [lower beds] and perhaps North Belmont.

This is substantially the same as that set out, as their joint views, by Pritchard (12), except that the clays and limestones of Curlewis and Belmont are there included under No. 2, as a sub-heading, and that North Belmont is omitted under No. 3, which is termed Lower Eocene and stated to be equivalent to the Lower Aldinga series in South Australia and probably to the Table Cape beds in Tasmania.

Within a year, in a rejoinder to Tate and Dennant's criticism (184), Hall and Pritchard withdrew (107) the Waurn Ponds

limestone as a separate type, and associated it, as well as North Belmont, with the Spring Creek beds, but referred the limestones of Batesford and the upper beds at Maude to the Southern Moorabool Valley beds, grouped with the lower beds of Muddy Creek. They maintained, however, their view that the Spring Creek beds were older than those of Muddy Creek, a sequence which they sought to support both stratigraphically and statistically.

Still later these authors made an important innovation in the proposal (112) of a local nomenclature, in connection with which they offered the following correlation:—

Werrikooian (Pliocene): Limestone Creek [type], Victoria.

Kalimnan (Miocene): Jimmy's [Jemmy's] Point, Gippsland [type]; upper beds at Beaumaris, Shelford and Muddy Creek, Victoria; and of the Murray River cliffs and at Aldinga, S. Australia. Also the marine sands of the Dry Creek and Croydon Bores, S. Australia [Adelaidean].

Balcombian (Eocene): Balcombe's Bay [type] and Grice's Creek, Mornington; Bairnsdale; Altona Bay; Corio Bay; Curlewis; Belmont; Lake Connewarre; Southern Moorabool Valley [Batesford, Fyansford, etc.]; upper beds at Maude; lower beds at Shelford; Murghebolue; Camperdown; Fishing Point, Aire River.

Jan Jucian [afterwards Janjukian] (Eocene): Spring Creek [type]; Waurn Ponds; lower beds at Maude; Cape Otway; and Aire Coast, Victoria. Lower beds at Aldinga, S. Australia. Table Cape, Tasmania.

The omission of the Muddy Creek lower beds is probably accidental, since these were always referred to the Balcombian by these authors. The inferior position of the Spring Creek beds is contrary to the view of McCoy, Tate and Dennant, though the two latter associated the Cape Otway and lower Aldinga beds at the base of their sequence.

Views of Chapman and his Associates.

McCoy's views as to age and sequence were substantially those advocated for many years by Chapman, as palaeontologist to the National Museum, Melbourne, who in 1914 (22, 23, p. 50) set out his views, which may be thus summarized:—

Oligocene (Balcombian): Mornington (Balcombe's Bay and Grice's Creek); Muddy Creek (lower beds, at Clifton Bank); lower part of the bores at Sorrento, Altona Bay and Newport; all in Victoria.

Miocene (Janjukian): Spring Creek, Torquay; Bairnsdale; Flinders; middle beds of Sorrento bore; lower beds at Flemington [Royal Park]; Keilor; Corio Bay, Fyansford, Moorabool Valley and Batesford; Curlewis; Waurn Ponds; Birregurra; Camperdown; Grange Burn limestone; Mallee bores; in Victoria. Mount Gambier, Murray River, Murray desert, and lower beds at Aldinga, South Australia. Table Cape, Tasmania.

Of these he thought (22, p. 299) that the Corio Bay, Bairnsdale and Fyansford beds probably represented the basal part of the

Miocene, to the middle of which he referred those of Torquay and Batesford, which latter, however, had already been shown by Hall and Pritchard to underlie the Fyansford deposits.

Lower Pliocene (*Kalimnan*): Gippsland Lakes (Jimmy's Point); upper beds of Shelford, Muddy Creek, and bores at Sorrento and Mallee; lower Glenelg River, Victoria. Adelaide and upper beds at Aldinga, S. Australia.

Upper Pliocene (*Werrikooian*): Limestone Creek, Glenelg River; upper beds of Moorabool Viaduct and Sorrento bore, Victoria; and Murray basin, S. Australia.

In 1923 similar views were set out in greater detail by Chapman and Singleton (27), who regarded the bulk of the Tertiaries of South-eastern Australia as Janjukian and chiefly Lower Miocene; the Balcombian as Oligocene; the Kalimnan, with which were included the upper marine beds of Adelaide (later the type locality of the Adelaidean), as Lower Pliocene; and the Werrikooian as Upper Pliocene.

Thus in Chapman's view, maintained up to 1934, not only was the Balcombian antecedent to the Janjukian (270, p. 20) but coeval with the latter, of Miocene age, were the thick lignites of Yallourn (subsequently type Yallournian) and the earlier volcanic rocks known in Victoria as the "Older Basalt."

Two years previously, however, Sir Edgeworth David, in the explanatory notes to his new geological map of Australia (2, table I. and footnote p. 89), had on Chapman's authority placed the lowest beds of the Aldinga section, formerly correlated with the Janjukian, in the Oligocene and thus in the inferior position assigned to them by Tate more than half a century earlier.

Meanwhile the present author, largely as a result of studies, begun in collaboration with Chapman, of the Tertiary faunas of Fyansford and elsewhere in the Barwon River basin, had gradually become convinced that they were referable to the Balcombian, as had initially been claimed by Hall and Pritchard, and, by implication, McCoy, instead of to the Janjukian as had been maintained by Chapman since 1914. Since the author accepted the correlation of the lower Maude beds with the type Janjukian, and also the stratigraphic sequence between Maude and Fyansford first established by Hall and Pritchard, he was forced to accept also their view that Balcombian must succeed Janjukian, though he still agreed with Chapman and most of the workers of the past 25 years that both (comprised in the inclusive term Barwonian) were post-Eocene.

Consequently, in an outline of Victorian geology prepared late in 1934, the author (17) referred the Janjukian to the lowermost Miocene, the Balcombian to lower to middle Miocene, the Kalimnan to lower Pliocene, and the Werrikooian to the top of the Pliocene. The lignites of E. Victoria, under the term Yallournian, were classed as Oligocene, as was also the Older Basalt series.

Early in the following year Chapman, then Commonwealth Palaeontologist, and Crespin (26), gave a very full correlation of localities, but refrained from using the terms Balcombian and Janjukian, though they continued the use of Kalimnan and Werrikooian. Nevertheless the type localities of these two stages, Balcombe Bay and Torquay, above Spring Creek ledge, are both classed as Lower Miocene, while the beds below this ledge, which occurs in the lower part of the type Janjukian, are placed as Upper Oligocene, though qualified by the remark that the mollusca are typically lower Miocene and that "it may eventually be proved that the first 10 feet [from the base] of the Bird Rock Cliff section [i.e. type Janjukian] is a passage bed between the Upper Oligocene and Lower Miocene" (26, p. 121).

Thus it may be deduced that Chapman has largely reversed his views up to that date as to the sequence of these divisions of the Barwonian, since these authors now correlate the greater part of the type Janjukian with the type Balcombian, but consider the base of the former slightly antecedent to the Balcombe Bay beds, with which they now also group Fyansford and other disputed localities which Chapman had asserted to be post-Balcombian and to be referable to the Janjukian. They also regard Upper Oligocene and Lower Miocene as present in the lower Aldinga beds, S.A. It will be seen that Chapman and Crespin's view does not greatly differ from that of the present author, except as regards the supposed equivalence of the greater part of the Janjukian with the Balcombian, but that it does greatly differ from that previously expressed by Chapman and Singleton in 1923 and by the former (270, p. 20) as recently as 1934.

Still more recently the present author (44) has suggested that the Adelaidean horizon, referred by Hall, Pritchard, Chapman and Singleton to the Kalimnan, might be interpolated, as Middle Pliocene, between it and the Werrikooian, an intermediate position first assigned to these beds, though as Lower Pliocene, by Tate.

Summary of the Correlation of the Marine Deposits.

Eocene.

Paleocene to Middle Eocene horizons are as yet unknown in Australia, the earliest marine beds being those discovered in 1934 between Giralia and Bullara, near the head of Exmouth Gulf in North-west Australia. These are foraminiferal and bryozoan limestones, often with rolled quartz grains, forming a thin series (10 feet-30 feet?) overlying, apparently disconformably, the Upper Cretaceous Cardabia series which may be Campanian in its upper part (*sed vide infra*, p. 57).

The two occurrences at present known are at the northern end of the Giralia Range, a shallow anticlinal structure whose eastern

limb has been eroded through the Tertiary beds into the underlying Cretaceous (73, 74, 156). Both localities are near the Giralia-Bullara road: one on the east flank of the Giralia anticline where the track to Bullara crosses the first low hills, the other in the bed of a creek at track crossing, nine miles from Bullara. At both the characteristic foraminiferal genus is *Discocyclina*, accompanied at the former by *Pellatispira* and *Asterocyclina*, at the latter by *Pellatispira* and *Nummulites*. These foraminiferal faunules have been referred by Chapman and Crespin (306) to the middle and upper parts of stage *b* of the East Indian sequence, which is approximately Upper Eocene. They thus represent a stage, as yet unknown in South-eastern Australia, which may conveniently be referred to as Giralian.

Friable *Discocyclina* limestones have been reported still more recently (78) from Red Bluff and Cape Cuvier, more than 100 miles to the S.S.W.

The discovery near Merlinleigh Homestead, 115 miles east of Cape Cuvier, of an internal mould in ferruginous sandstone described by Miller and Crespin (569) as *Aturia* cf. *ziczac* (Sowerby), suggests that the Eocene may have once extended over a hundred miles inland from the present coastline.

In South-west Australia soft calcareous shales from deep borings in King's Park and elsewhere near Perth, have recently been referred by Parr (338) to the Upper Eocene on the evidence of a very different foraminiferal faunule, which combines species identical with or similar to restricted Eocene forms in America, such as *Dentalina colei*, *Bolivinopsis eocenica*, and *Discorbis assulatus*, with a slight Oligocene element, including *Cyclammina incisa*, first described from the Lower Oligocene of New Zealand, and not uncommon in the Oligocene of Victoria.

Oligocene.

Limestones in the Cape Range, south of North West Cape, first recorded by Chapman (301) as Oligocene, largely on the identification of *Lepidocyclina* (*Eulepidina*) *dilatata*, were subsequently regarded as younger by Crespin (78), who reported also the eulepidines *L. papuanensis* and *L. chapmani*. But according to Umbgrove (Leidsche Geologische Mededeelingen, Deel V., p. 69, 1931), *L. papuanensis* belongs to the horizon Tertiary *d* in the East Indies, being found in the Tempilan beds of East Borneo, and this horizon in the Cape Range is here referred to the Upper Oligocene.

In Victoria, *Lepidocyclina* first appears on a later horizon, regarded by Chapman and Crespin (26) as Lower Miocene, but underlying it are beds which they have referred to the Upper Oligocene, including the micaceous foraminiferal marls with *Cyclammina* and *Victoriella* (as well as the underlying oil-bearing glauconite bed) of the lower part of the deep borings of the East

Gippsland area, and similar beds in bores at Portland and in N.W. Victoria. As already noted, they also included as Upper Oligocene the base of the Janjukian at its type section, together with the Aire coastal sections in Victoria and the lower part of the lower Aldinga beds in South Australia.

All these are regarded by the author as referable either to the Janjukian, as basal Miocene or possibly the summit of the Oligocene, or to an as yet unnamed pre-Janjukian stage, probably to be regarded as high in the Oligocene, and with them may be placed part of the marine beds of the Torquay bore, at the type Janjukian locality.

Underlying them in turn are the so-called lignitic beds, which are carbonaceous sands and clays apparently chiefly of estuarine origin, at the base of the East Gippsland, Torquay, Dartmoor, and Mallee bores in Victoria, and underlying the marine lower Aldinga beds and elsewhere in South Australia. These are referred to the Oligocene by the author, and to the Lower Oligocene by Chapman and Crespin. South-west of Torquay they outcrop, as dark carbonaceous sands with *Cyclammina*, in cliff sections (102) east of Anglesea, whence they may be termed Anglesean.

Miocene.

Chiefly referable to the earlier Miocene, but perhaps in part extending back into the Oligocene, is the main development, both in thickness and in geographic distribution, of marine Tertiary strata in Australia.

In the North West Division of Western Australia they are best developed in the North West Cape Range, on the eastern side of which are limestones 550 feet in thickness with abundant Lepidocyclinae (74). In addition to the eulepidine horizon above referred to the Upper Oligocene is one in which the eulepidines *Lepidocyclina murrayana* and *L. insulaenatalis* are associated with the nephrolepidines *L. angulosa*, *L. ferreroi*, and *L. verbeeki* and *Cycloclypeus* (78). This is Lower Miocene, to be correlated with the upper part of Tertiary *e* of the East Indies, and slightly older than the Batesfordian of Victoria. Overlying these are white foraminiferal limestones about 60 feet thick, apparently also Miocene, and still higher well-bedded white limestones 100 feet thick, of uncertain age (74).

Foraminiferal and bryozoan limestones also occur in the Rough, Giralia, and Waroora Ranges, and extend southwards to Salt Lake, north of Shark Bay, a total distance of nearly 160 miles.

From the Cape Range and Rough Range areas, and from borings at Carnarvon, Miss Crespin (78) has referred to the Middle Miocene foraminiferal limestones with, in addition to nephrolepidines, *Marginopora vertebralis*, *Flosculinella bontangensis*, and the widespread *Trillina howchini*, first described (343)

from the lower Muddy Creek beds (Balcombian) of Victoria. These suggest a correlation with Tertiary *f* of the East Indies.

Still further south, at Champion Bay near Geraldton, marine Tertiary rocks of varied lithological types (7) form a coastal strip of which little is known.

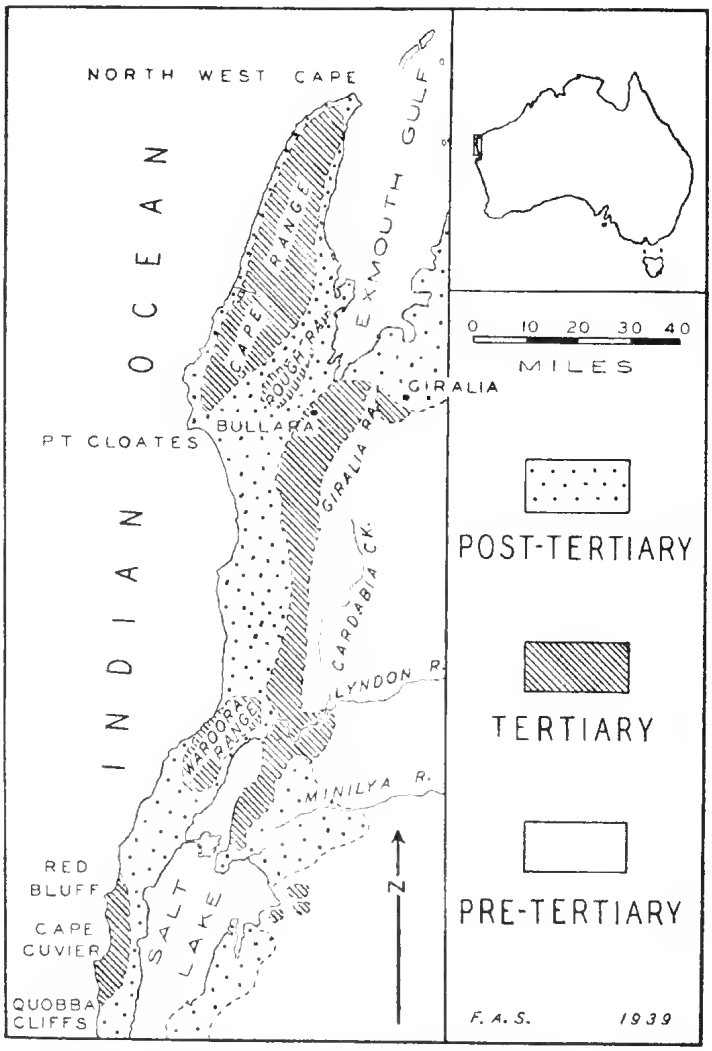


FIG. 1.—Tertiary rocks of North West Australia. Modified from Raggatt, 1936 (156, pl. 3).

In South Western Australia the Plantagenet beds (7, 8, 133) are developed along the south coast near Albany, and from Cape Riche to the Phillips River. They consist chiefly of siltstones with a maximum thickness of 300 feet, resting upon granite, and

contain siliceous sponges and a small molluscan faunule (66, 271) with relations to the Janjukian of S.E. Australia. About 250 miles N.E. of Cape Riche, small exposures occur 120 miles inland near Norseman (8, 97), resting on pre-Cambrian rocks at 900 feet above sea level. They are mostly limestones with poorly preserved mollusca and bryozoa, except at Princess Royal, where silicisponge spicules (347) occur in a siliceous rock.

On the southern coastline Tertiary limestones are believed to extend from Israelite Bay, past Point Culver and Twilight Cove, to Wilson's Bluff near Eucla, where they pass into South Australia and reach as far as the Head of the Great Australian Bight, a total distance of about 500 miles. Little is known of this great limestone plateau, extending inland beneath the Nullarbor Plains and believed to cover an area approximating to that of Victoria. Over most of this western part of the Great Australian Bight the high cliffs show apparently horizontal strata, chiefly the Eucla limestone (7).

At Wilson's Bluff (172) this comprises from below 188 feet of chalky white bryozoan limestone with two layers of flints and with echinoids, including *Salenia tertiaria*, becoming harder in its upper part, rich in brachiopoda, chiefly "*Magellania*" *insolita*; 12 feet of yellow bryozoan limestone with *Cellepora*; and 50 feet of grey to brown crystalline limestone with molluscan casts. Tate correlated the first two with the lower Aldinga beds of South Australia, and the third with the upper Aldinga beds, which are usually regarded as Kalinman. The author believes the crystalline limestones may, however, correspond with those of Ooldea (58), near the north-eastern limit in South Australia of the Nullarbor Plains, which are certainly pre-Kalinman. In deep borings inland in Western Australia the Eucla limestone is reported to attain a thickness of 500 to 900 feet, when its lower portion might well range down into the Oligocene; it is, however, possible that these bores may have entered Cretaceous rocks.

In South Australia bryozoan limestones are found on Yorke Peninsula (52, 121, 176, 186) as well as on Kangaroo Island (116, 118, 174) and on the east side of Gulf St. Vincent (69, 122, 185) from Gawler southward to near Sellick's Hill. Fossiliferous sands and clays occur in deep borings near Adelaide (180), and outcrop in the lower part of the cliffs at Aldinga Bay (122, 185). These, with the Cape Otway clays (110, 184) in Victoria, are regarded by the author (44) as either Janjukian or less probably referable to the stage which precedes it.

In the south-east of South Australia are the limestones and calcareous sandstones exposed along the River Murray cliffs (169, 175), of which the middle beds are doubtfully Balcombian, and cut by borings in the Murray Plains (68, 123, 182), while bryozoan limestones outcrop at Mount Gambier (190), whence they pass into Victoria.

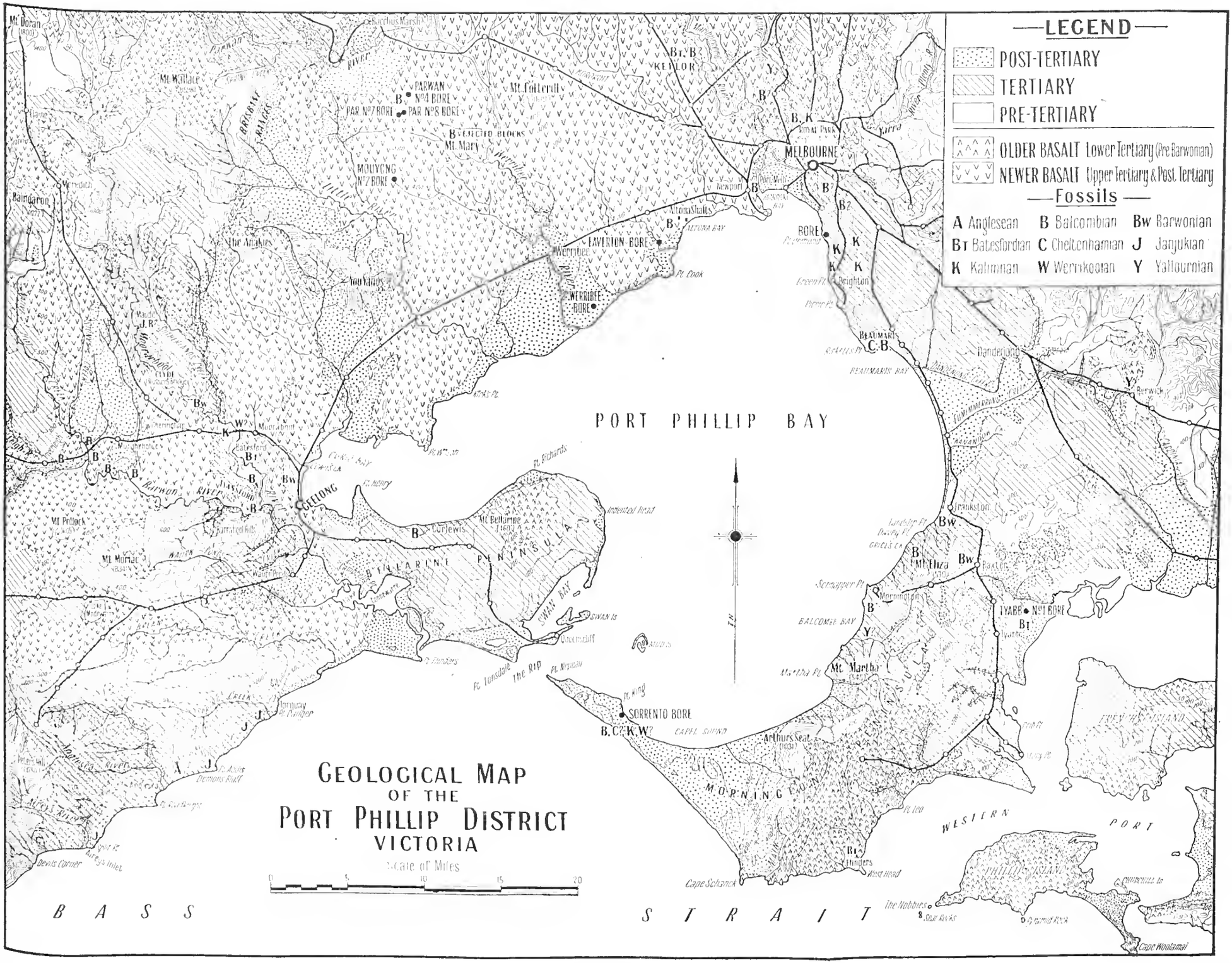
Portions of the ancient "Murray Gulf" extend into New South Wales, where Janjukian beds were cut at 647 feet in the Arumpo bore (94) and at 420 feet in the South Ita bore (44, 134), the latter 65 miles south of Broken Hill, and into Victoria, known by numerous borings in the Mallee and Wimmera districts. In Victoria, in addition to this north-western area, the principal regions of deposition are in the south west, more or less continuous beneath a basalt cover with that of South Central Victoria, and in East Gippsland in the south-east of the State.

Two main stages are recognizable in Victoria, which together constitute the *Baraconian System*, chiefly Miocene but perhaps extending back into the Upper Oligocene.

The earlier, in the author's view, is the *Janjukian stage* or group, typified by the lower beds (shelly clays and glauconitic marls) and upper beds (bryozoan limestones) of Bird Rock cliffs near Torquay (107, 183, 184). Near the base of the section, which is about 180 feet in thickness, are beds with *Spirulirostra curta*, closely related to the Miocene genotype *S. bellardi*, and a boring has proved a further 170 feet, giving a total thickness of about 350 feet. In Victoria the lower Maude beds (23, 106, 184), and in Tasmania the Table Cape beds (6, 131, 150, 166, 185), with *Prosqualodon davidis* (595-597), are here placed in the Janjukian, as Lower Miocene or even Oligo-Miocene, as are less certainly the Cape Otway and Aire Coast sections (50, 110, 184). Less than 1 per cent. of the Janjukian molluscan fauna of about 250 species is still living.

The later or *Balcombian stage* is based on 35 feet of shelly marls, with an equal thickness proved by boring, at Balcombe Bay (111, 114, 135) near Mornington, Port Phillip, with similar beds at Grice's Creek (111, 135) nearer Frankston, and on the Mitchell River (91), Gippsland; in depth at Altona (23, 72, 108, 187) on Port Phillip and north-westerly towards Parwan (38); Murgheboluc (113), Fyansford (104), etc., in the Barwon River Basin; Gellibrand River (183); and lower beds at Muddy Creek (23, 83, 183) near Hamilton in Western Victoria. Here the marls contain over 400 species of mollusca, of which *Aturia australis*, closely related to the European *A. aturi*, and a new species of *Spirulirostra* are noteworthy, as is the pelagic miliolid *Trillina howchini*, known in the Miocene of Java (Tertiary *e*), Borneo (Tertiary *e* and *f*?), Phillipines, Pemba I. near Zanzibar, Irak, and I. of Paxos in Greece (273). They are rich in *Amphistegina lessonii* and the pteropod *Vaginella eligmostoma*, and are shown by a boring to be underlain by limestones with Lepidocyclinae, which outcrop nearby on Grange Burn.

The Batesford limestone (104, 299) with similar Lepidocyclinae, the commonest of which has been regarded as *Lepidocyclina tournoueri* (299), for which the term Batesfordian was



MAP 2.

Geological Map of the Port Phillip district, Victoria. Modified from map in A.N.Z.A.A.S. Handbook for Victoria, 1935.

proposed (27), is similarly overlain by the Fyansford clay, here referred to the Balcombian.

The Batesfordian is thus either a late Lower or early Middle Miocene stage, also represented at Keilor (77), Flinders (27, footnote p. 989; 137), and in the East Gippsland bores (25), (characterized by nephrolepidines and a trybliolepidine but no eulepidines, and probably to be correlated with part of the East Indian Tertiary *f*), which immediately precedes the Balcombian (the view here adopted), or it may ultimately prove to be merely a calcareous facies of the latter. In either case a Middle Miocene age is probable for the Balcombian, of which a littoral facies may be represented by the limestones of the upper beds at Maude (106) and the ironstones of Keilor (77, 108) and the lower beds at Royal Park (70, 108, 158) near Melbourne.

The Balcombian mollusca of the type locality total about 300 species, of which living species are not more than 1 per cent.

To some part of Barwonian time belong the bryozoan limestones of King (55, 80) and Flinders Islands (132) in Bass Straits and near Cape Grim (6, 10) and Marrawah (10) in North-West Tasmania.

The Upper Miocene may be represented in many cases by the stratigraphic break, marked by a "nodule bed" or rarely a slight angular unconformity, at the base of the Kalimnan (Lower Pliocene) where it rests on Barwonian deposits. Perhaps Upper Miocene in part are white limestones on the western side of the North West Cape Range in Western Australia (74), and the beds immediately underlying the Kalimnan of the Sorrento (63) and East Gippsland (25) bores in Victoria.

A probably Upper Miocene stage, which may be distinguished as Cheltenhamian, can be based on the marine ferruginous sands, overlying Balcombian clays just below low-water mark, of the cliffs at Beaumaris, near Cheltenham, Port Phillip (71, 108). These upper beds have usually been referred to the Kalimnan (Lower Pliocene), largely on the mollusca, but an Upper Miocene age is suggested by teeth of the cetacean *Parasqualodon* and by the presence of *Aturia*, a cephalopod elsewhere not surviving the Miocene.

Pliocene.

In North Western Australia this is doubtfully present in the limestones above-mentioned in the western side of the Cape Range, which have been provisionally termed Mio-Pliocene (74).

In South-Eastern Australia three stages have been proposed, and a fourth probably remains to be recognized.

The *Kalimnan stage* (Lower Pliocene) is based on the sandy clays of Kalimna (85, 90) in East Gippsland, which, with an extension in bores, are about 150 feet thick. To it are referred

sands and marls of the upper part of the borings of East Gippsland (25), Sorrento (63), the Mallee (57) and Wimmera districts, of outcrops at Muddy Creek (upper beds) (83, 272), in Victoria; and more doubtfully the upper beds of the Murray Cliffs (175) and of Aldinga (185) in South Australia. They are neritic deposits of whose molluscan species, totalling about 110 at Kalimna and more than 150 at Muddy Creek, perhaps 10 per cent. are still living.

The *Adelaidean stage*, known only in borings beneath the Adelaide Plains, South Australia, is based on the fossiliferous marine grey to white sands, about 160 feet thick, cut at about 300 feet below sea level in the bores at Dry Creek (177), the Abattoirs (126), and elsewhere (124, 125). They are shallow water deposits whose molluscan fauna, with perhaps 20-25 per cent. of living species in a total of about 200, shows more relationship with the Kalimnan, with which it has often been correlated, than with the Werrikooian. Nevertheless, it is probably post-Kalimnan, a conclusion supported by the foraminiferal faunule, and it may be tentatively regarded as Middle Pliocene (44).

The *Werrikooian stage* is typified by shallow water shell beds, on the Glenelg River near Limestone Creek, in Western Victoria (82, 84, 159), of whose molluscan fauna of about 200 species about 95 per cent. are still living, and may be placed at the top of the Pliocene, with a gap representing an as yet undiscovered stage or stages between it and the Adelaidean. This basal shell bed is not more than a foot in thickness, and is conformably overlain (159) by the Ostrea Limestone (84, 183), a series of 30 to 50 feet of flaggy sandy limestone, often false-bedded, widespread in south-west Victoria from Portland to the South Australian border, and notable for the first appearance of *Pecten* (*Notovola*).

Doubtfully correlated with the Werrikooian are beds at Moorabool Viaduct (144) and in the Sorrento (63) and Mallee (57) bores, in Victoria; in a bore at Wingaroo (10, 26, 44, 526), Flinders Island, Bass Straits; and in the Tintinara bore in South Australia (57, 68, 123, 179); but demarcation from marine Pleistocene is often difficult.

Near Moruya on the south coast of New South Wales are ferruginous grits with poorly preserved shell moulds for which the author has with some doubt suggested an Upper Cainozoic age (21, p. 337; 653, p. 41).

Definition and Discussion of Stage Names.

The following system and stage names have been proposed, or are herein suggested, for subdivisions of the Australian marine Tertiary strata:—Adelaidean, Aldingan, Anglesean, Balcombian, Barwonian, Batesfordian, Cheltenhamian, Gambierian, Giralian,

FIG. 2.—Geological map of Adelaide district, South Australia, with sites of bores cutting Adelaidean beds. Contours from Adelaide sheet, Military Survey of Australia, 1915.

Hamiltonian, Janjukian, Kalimnan, Murravian, Werrikooian, to which may be added Eyrian and Yallournian, proposed for non-marine deposits.

Adelaidean Stage.

Proposed by Howchin (4, p. 423) in 1928 for beds which in South Australia "are only known by borings, and as these are situated within short distances of Adelaide, it is proposed to distinguish them as the Adelaidean Upper Pliocene . . . . The presence of this marine bed has been proved by borings at Croydon, Dry Creek, the Abattoirs, Salisbury, and Smithfield; also on the coastal plains to the north of Adelaide, at St. Kilda, north of the Outer Harbour, and at Kidman's Bore, 3 miles to the northward of the last-named bore. The bed is richly fossiliferous."

The best known of these borings, palaeontologically, are the Dry Creek bore, 5 miles north of Adelaide, and the Metropolitan Abattoirs bore, about $1\frac{1}{2}$ mile to the east of Dry Creek. For the Dry Creek bore, from the surface at 14 feet above sea level, Tate (177, p. 172) gives the following sequence, the present writer's comments being added in brackets:—

0–120 feet. Clays. Pliocene or Mammaliferous Drift. [Recent to Pleistocene.]

120–320 feet. Sands. Not examined by Tate. [? Pleistocene.]

320–410 feet (bottom of bore). Fossiliferous sands. Older Pliocene. [Adelaidean].

For the Abattoirs bore, commencing at about 100 feet above sea level, the sequence described by Howchin and Parr (126, p. 289) is as follows:—

0–341 feet. Alluvial sand and gravel. Recent to Pleistocene.

341–500 feet. Fossiliferous marine sands. Upper Pliocene. [Adelaidean.]

500–820 feet (bottom of bore). Fossiliferous clays and calcareous sandstones. Miocene. [Barwonian.]

While similar beds have been reported by Tate (180) in the Croydon bore, by Howchin (124, 125) in the Brooklyn Park, Glanville and Cowandilla bores, and by Mrs. Ludbrook (140) in the Hindmarsh bore, all in the vicinity of Adelaide, the most suitable type sections, since unfortunately bore sections are all that are available, are those given by the two borings first mentioned.

The Adelaidean may be defined as the interval of time represented by the deposition of the fossiliferous marine sands cut at 320 *to* 410 *feet* (306 *to* 396 *feet below sea level*) *in the Dry Creek bore and at* 341-500 *feet* (*about* 241-400 *feet below sea level*) *in the Abattoirs bore, as well as those represented therein by non-deposition or erosion.*

In the Dry Creek bore the foraminifera were determined by Howchin (in Tate, 177, p. 177) and the mollusca by Tate (177, pp. 174-177), while for the Abattoirs bore the foraminifera have been exhaustively treated by Howchin and Parr (126), the

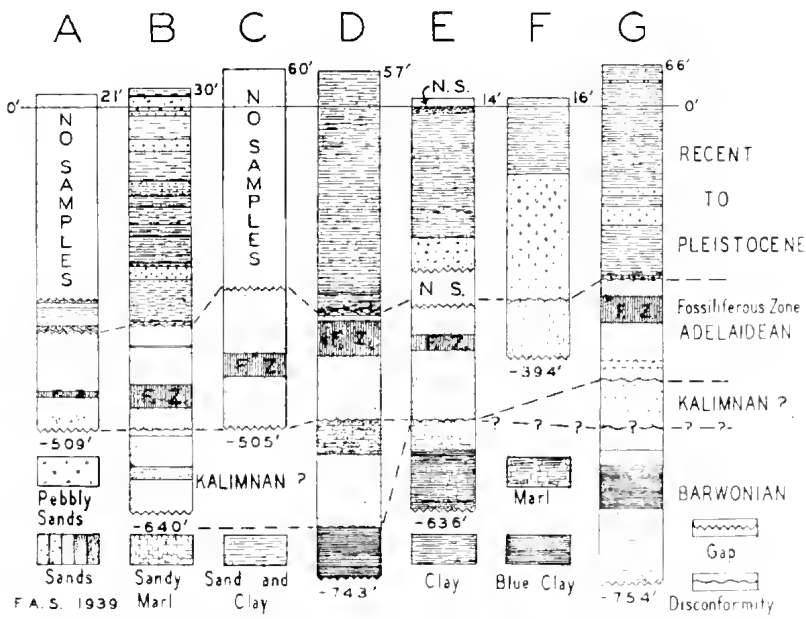


FIG. 3.—Comparative sections of Adelaidean beds near Adelaide. A, Brooklyn Park bore (124), B, Cowandilla bore (125), C, Hindmarsh bore (140), D, Croydon bore (178), E, Glanville bore (124), F, Dry Creek bore (177), G, Abattoirs bore (126).

bryozoa by Stach (431), and the pelecypods listed by N. H. Woods (549, pp. 150-151). From these and other sources, a list of the characteristic fossils, in which the nomenclature, but not the identifications, of the mollusca has been revised, appears to be:—

Foraminifera: *Flintina triquetra* Brady.

Pelecypoda: *Glycymeris convexa* (Tate), *Ostrea sinuata* Lamarck, *Chlamys asperrimus antiaustralis* (Tate), *Codokia nuciformis* (Tate), *Miltha* (*Milthoidea*) *grandis* (N. H. Woods), *Lepton trigonale* Tate, *Chioneryx cardioides* (Lamarck), *Electromactra howchiniana* (Tate).

Gasteropoda: *Turritella* (*Ctenocolpus*) *trilix* Cotton and Woods, *Tylospira marwicki* (Finlay), *Neodiastoma provisi* (Tate), *Polinices balteatella* (Tate), *Cymatiella sexcostata* (Tate).

Aldingan Stage.

Though the introduction of this name has been attributed to Tate by Chapman (57, p. 409) and by Chapman and Singleton (27, p. 985), that author at the reference cited (47, p. liii) uses only the terms Lower Aldinga Series and Upper Aldinga Series, in a correlation table of South Australian Tertiary strata. In one of his last papers, Tate (181, p. 107) in a Succession Table, again referred to the Lower Aldingian Series, which he subdivided under Lower, Middle, and Upper Eocene, the Middle Eocene including the "middle section of Lower Aldingian." It is clear from the context, however, that Tate used the term Lower Aldingian not as a stage name but only as a convenient method of referring to the lower beds at Aldinga, which he had originally described still earlier (171, p. 121).

The first usage as a stage name, in the amended form Aldingan, is therefore that of Hall and Pritchard (112, p. 79), who observed—"In the cliff sections, as described by Messrs. Tate and Dennant, 'Miocene' overlies 'Eocene,' and the term Aldingian as used by them includes both sets of strata. If it be confined to the lower series only, it might perhaps be employed, though it violates the principle that a name should not be given where two distinct series are in contact. As we differ from the views of Messrs. Tate and Dennant on the question as to its equivalence or otherwise with the Spring Creek series, a type name may be thought desirable, though our own views are opposed to its use."

This correlation by Hall and Pritchard of the lower beds of Aldinga with the beds of Spring Creek (type locality of the Janjukian stage) was accepted by Chapman (23, pp. 50, 51; 57, p. 409) and by Chapman and Singleton (27, p. 986), though Tate (181, p. 107) had placed the Spring Creek beds on a later, "post-Eocene," horizon. Apparently Chapman and Crespin (26, p. 125) would place part of the lower beds at Aldinga on a slightly earlier horizon than those of Torquay (i.e., Spring Creek), and the writer has also considered this possibility (44).

If the term Aldingan be used for a stage it seems necessary that it should be confined in meaning to the Lower Aldinga Beds, which was, in fact, the restricted sense employed by Tate and Dennant (185, p. 141) when referring to the "Aldingian fauna."

As it has been used in two senses, as Hall and Pritchard, the introducers of the term, were opposed to its use, and as doubt exists as to its equivalence or otherwise with the Janjukian, it seems wiser to reject, at the present time, the Aldingan as a stage name.

Anglesean Stage.

Here proposed for the black sandstone and sandy clays of the coastal cliffs extending from near the mouth of the Anglesea River east-north-easterly for about 2 miles towards Point Addis,

in the Parish of Jan Juc, Victoria. At Demon's Bluff, near the centre of the section, the cliffs are over 250 feet in height, but are much scarred by landslips, and the relations of the beds are more clearly seen towards the Anglesea end.

On the axis of a gentle anticline, about a third of a mile north-east of the mouth of Anglesea River and half a mile east of the Anglesea bridge, a nearly vertical cliff section shows 41 feet of black sandstone overlain by 47 feet of white sands. The junction between them, at a spot 150 yards to the south-west, dips at 4½ degrees to the north-west. The dark-coloured somewhat carbonaceous sandstone commonly shows lighter coloured branching markings which are presumably algal, while locally the foraminiferal genus *Cyclammina* is abundant and, with the tooth of *Odontaspis contortidens* Agassiz recorded by Hall (102, p. 47), attests the marine origin of these poorly fossiliferous beds. The absence of a rich shelly fauna renders the locality by no means ideal as a type section, but nearly all other occurrences of beds correlable with the Anglesean, as in the East Gippsland, Mallee, and Dartmoor areas, are known only from borings and are thus unsuitable for selection.

The upward limit of the Anglesean is given by the overlying unfossiliferous white sands, but its downward extent, in the absence of borings, remains uncertain.

The Anglesean may be defined as the interval of time represented by the deposition of the dark-coloured sands with Cyclammina *of the cliff sections between Anglesea and Point Addis, as well as those represented therein by non-deposition or erosion.*

Balcombian Stage.

This was introduced in 1902 by Hall and Pritchard (112, p. 78) as follows: "*Balcombian.* The clays and limestones of Balcombe's Bay contain another distinct fauna. The beds are sometimes spoken of as at Mornington, but the locality we give is more exact."

At the type locality, which is a coastal section on the eastern shores of Port Phillip, Victoria, immediately to the north of the old cement works near the northern end of Balcombe Bay, and about a mile and a half south of Mornington, the fossiliferous clays or marls, with interbedded concretionary hard limestone bands, have been described by Hall and Pritchard (111, p. 39).

The richly fossiliferous marls are exposed chiefly between tide marks, but fossils become scarcer and more fragile in the cliff section, in which the marls have a thickness of about 35 feet. They are overlain by ferruginous sands and grits, with which the junction is sharp but even. Boring has shown the calcareous

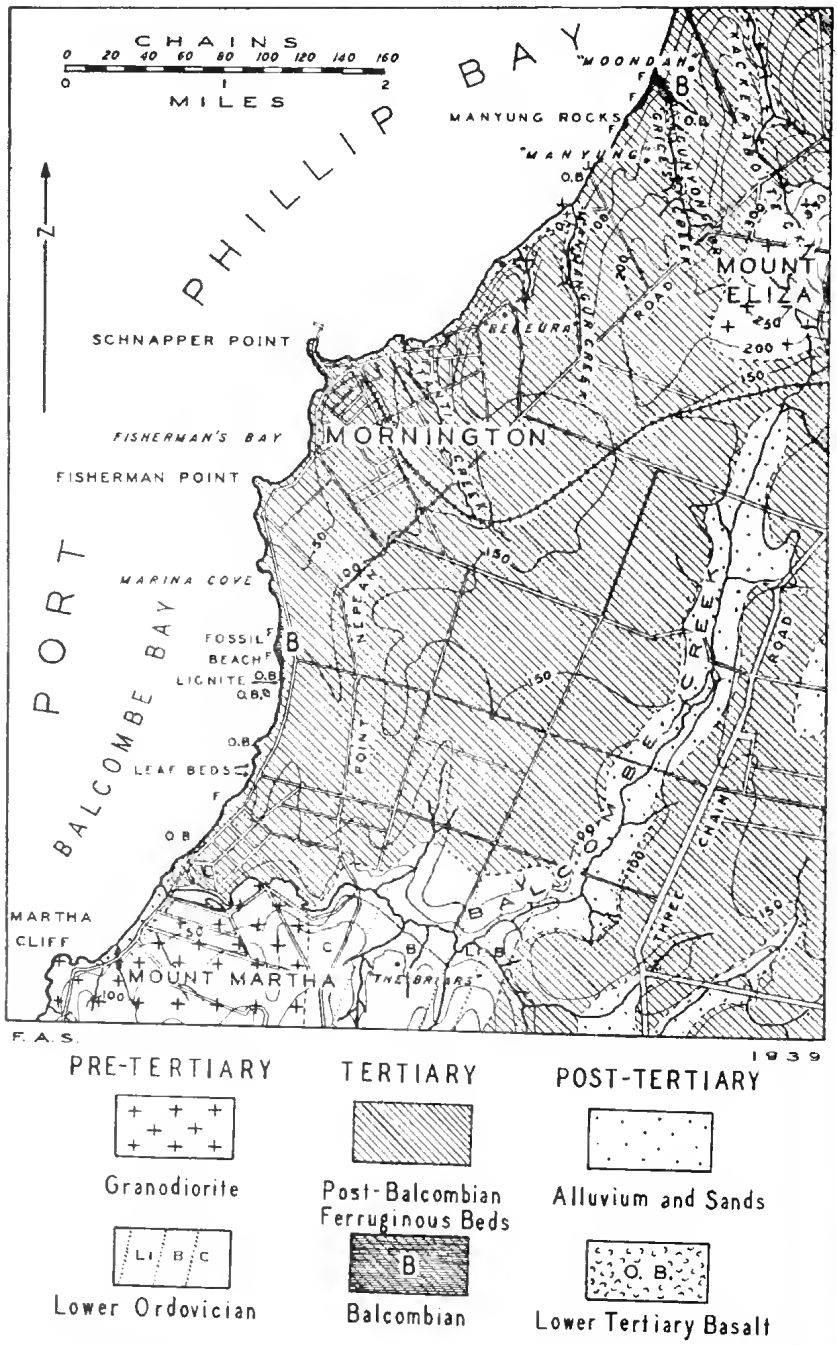


FIG. 4.—Geological map of Mornington district, Victoria. Modified from Kitson, 1900 (135), and unpublished mapping by R. A. Keble. Contours from Cranbourne sheet, Military Survey of Australia, 1912. J, Jurassic; F, Balcombian fossils.

marl to persist for 35 feet, and to be succeeded in depth by sandy clays, sands, and ligneous clays, and this apparently non-marine series is in turn underlain by basalt.

It is clear that from the original description the ferruginous series, though subsequently referred to the Balcombian by Pritchard (155, p. 937), must be excluded from the definition of the stage, though it is reasonable to include the extension in depth of the calcareous marl proved by the boring, Bore No. 6, Parish of Mooroodue (36, p. 30).

The cliff section (k-p) beach floor (h-j), and bore (a-g) give a sequence as follows, totalling 197 feet.

(*p*) 5 feet mottled clay.
(*o*) 5 feet ironstone.
(*n*) 4 feet ferruginous sandstone.
(*m*) 2 feet ferruginous grit.
(*l*) 10 feet ferruginous fine sandstone.
(*k*) 35 feet grey clays with selenite crystals in upper part.
(*j*) 1 foot septarian limestone nodules.
(*i*) 3 inches grey shelly clays.
(*h*) 1 foot grey clays with discoloured markings of seaweeds (?).
(*g*) 35 feet calcareous marl.
(*f*) 17 feet sandy clay.
(*e*) 24 feet sand.
(*d*) 2 feet ligneous clay.
(*c*) 4 feet coarse sand.
(*b*) 33 feet ligneous clay.
(*a*) 19 feet hard basalt.

Depth bored 134 feet.

Beds (b)-(f) constitute 80 feet of apparently non-marine strata, perhaps to be referred to the Yallourn series; beds (g)-(k) a fossiliferous marine series totalling 72 feet, in which most Balcombian fossils come from the richest bed (i), though fossils also occur above and below; and beds (l)-(p) belong to a ferruginous series, here 26 feet thick, which is widespread on the Mornington Peninsula.

The Balcombian may be defined as the interval of time represented by the deposition of the grey marls and concretionary limestone bands constituting beds (g)-(k) in the above sequence at Balcombe Bay, as well as those represented therein by non-deposition or erosion.

At the type locality the foraminifera have been dealt with by Chapman and his colleagues (298, 307, 310) in a monograph of the Balcombian Foraminifera of Port Phillip; the bryozoa were listed by Maplestone (423); the mollusca by Hall and Pritchard (111), and the latter and other groups by Dennant and Kitson (275); in the last three cases under the name Mornington, which refers to this section, as do "Schnapper Point," "Mount Martha," "between Mount Eliza and Mount Martha," and even "Hobson's Bay," of the earlier authors.

Characteristic mollusca include:—

Pelecypoda: *Limopsis morningtonensis* Pritchard.

Gasteropoda: "*Cerithium*" *apheles* T. Woods, *Umbilia eximia maccoyi* Schilder, *Austrotriton textilis* (Tate), *Chicoreus lophocssus* (Tate), *Dennantia ino* (T. Woods), *Volutospina antiscalaris* (McCoy), *Bathytoma rhomboidalis* (T. Woods), *Conus ligatus* Tate.

Pteropoda: *Vaginella eligmostoma* Tate.

Cephalopoda: *Nautilus balcombensis* Chapman.

Less common but apparently restricted species include:—

Pelecypoda: "*Chlamys*" *dichotomalis* (Tate), *Eucrassatella dennanti* (Tate).

Gasteropoda: *Turritella* (*Colpospira*) *platyspira* T. Woods, *Gigantocypraea gigas* (McCoy), *Solutofusus carinatus* Pritchard, *Pterospira hannafordi* (McCoy).

Barwonian System.

In 1904 Hall and Pritchard (113, pp. 297-8) proposed this name, as a Barwonian Series, in these words: "In the paper in which we proposed the names Balcombian and Janjukian, we indicated the existence of certain beds which undoubtedly belonged to the older series comprised under these two names, which are clearly distinct from the younger Kalimnan, but which from the smallness of the collections available, we did not care to refer definitely to either Balcombian or Janjukian. In other words, the palaeontological differences between Balcombian and Janjukian series, though of importance, are not nearly so marked as between them and the Kalimnan. On these grounds we think it advisable that a name should be given which will comprise both Balcombian and Janjukian. The former series is extensively developed in the Barwon basin, and the latter at its typical exposure at Spring Creek, south of Geelong, is not far from the borders of the same basin, so that the name Barwonian is suggested."

The name is thus given to cover both Balcombian and Janjukian, and is *not* defined in terms of any type locality within the Barwon basin, in which the beds are, indeed, referred by these authors to the Balcombian. Chapman (57, p. 409) was therefore mistaken in believing the Barwonian to be "typified in the series from Red Hill, Shelford, through Inverleigh, Murgheboluc, down the Barwon valley to Fyansford," an error which had previously led him (56, p. 371) to discard the term Barwonian on the grounds that its members were included in the term Janjukian, to which he had referred (see Chapman and Singleton, 27, p. 986) the Tertiaries of the Barwon basin, instead of to the Balcombian as had done Hall and Pritchard.

The Barwonian may be defined as the interval of time represented by the Janjukian and Balcombian as herein defined, as well as such as may intervene between them.

Batesfordian Stage.

The first use of the term Batesfordian was in 1914 by Chapman, who stated (23, p. 49), in reference to the white polyzoal limestone in bore No. 11 of the Victorian Mallee district—"The fauna altogether showed a strong Aldingan and Batesfordian aspect; both Aldinga (lower beds) and the Batesford Limestone being of Janjukian age." Apparently Chapman had no intention of using the term as a stage name, for it is not included in the list of subdivisions of the Cainozoic beds given by him in his account of the Cainozoic Geology of the Mallee Bores (57, pp. 409-411).

Accordingly, the first formal proposition of the Batesfordian stage was by Chapman and Singleton (27, p. 986) in 1925, as follows:—"*Batesfordian.*—Typified by the foraminiferal and polyzoal limestones of the quarries on the Moorabool River near Batesford, in the Geelong district, Victoria. These have been referred to by one of us (F.C.) to the Janjukian, and by Hall and Pritchard to the Balcombian." Later in the same paper (27, p. 990), it is stated that "Another calcareous facies of the Janjukian, characterized by the abundance of *Lepidocyclinae*, is the Batesfordian, to which are referred the foraminiferal and polyzoal limestones of Batesford, near Geelong, the junction of Grange Burn and Muddy Creek, near Hamilton, Violet Creek (in the same district), Green Gully, near Keilor, and Cape Schanck and Flinders, to the south of Port Phillip. These Batesfordian localities have all been relegated to the Balcombian by Hall and Pritchard."

The writer has already indicated his belief (*supra*, p. 19) that the Batesfordian is a stage immediately antecedent to the Balcombian.

At the time of proposition of the name there were two limestone quarries on the Moorabool River, a little more than a mile south-east of Batesford. One, on the left bank of the river, is known as the Upper Quarry, from which was formerly obtained a building stone termed "Moorabool Stone," a brownish dense limestone consisting largely of Lepidocyclinae. Hall and Pritchard (104, p. 11) gave the hill section at this locality, from above downwards, as follows:—

"Basalt	75 feet.
Incoherent sandy material, with calcareous concretions ..	50 feet
Yellow clay, with calcareous concretions	5 feet.
Polyzoal limestone	20 feet.
Orbitoides [*recte* Lepidocyclina] limestone	20 feet.
Total:	175 feet."

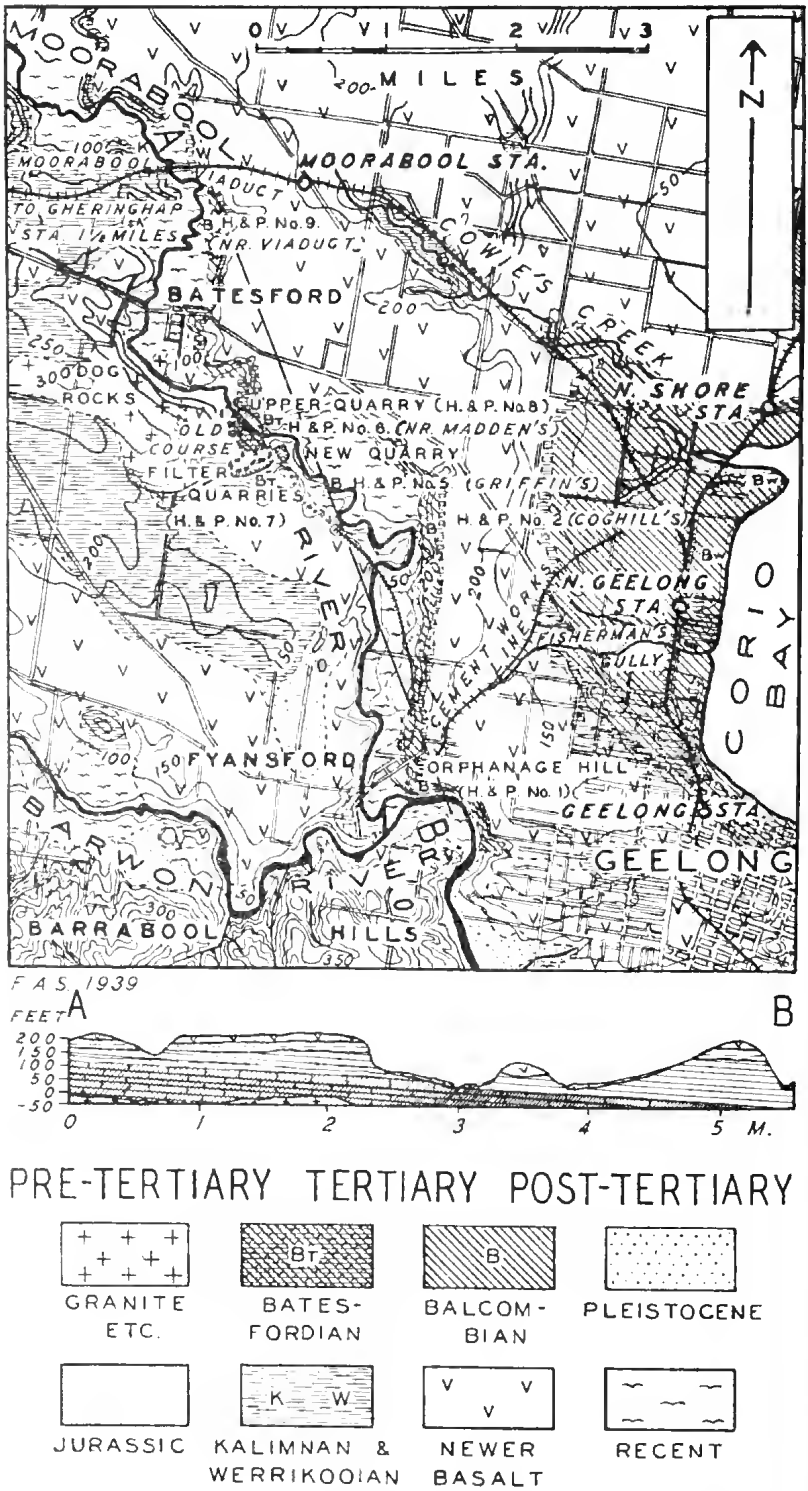


FIG. 5.—Geological map and section of Batesford district, near Geelong, Victoria. Modified from Quarter-sheets Nos. 24 N.E. and S.E., Geological Survey of Victoria, 1863, with emendations and additions. Contours from Geelong sheet, Military Survey of Victoria, 1914. Fossiliferous localities: B, Balcombian; Bt, Batesfordian; Bw, Barwonian; K, Kalimnan; W, Werrikooian.

[*Page 30.*

The other, on the right bank of the river about half a mile south of the building stone quarry, was known as the Dryden or Filter Quarries, formerly worked for lime-burning and cement-making, as well as for the manufacture of dripstone filters from the compact limestones at the base of the section. Chapman (299, p. 264) recorded the sequence, from below, as being 22 feet of pure white or cream-coloured friable limestone, composed largely of Lepidocyclinae, and gradually passing upwards into polyzoal rock with fewer Lepidocyclinae. Over this were 14 feet of fine-textured pale bluish clay.

Neither of these quarry sections is at present visible. The building stone quarry has been partly absorbed and partly covered by dump material from a greatly enlarged Upper Quarry adjoining to the south, formerly worked by Australian Cement Ltd. The Filter Quarries have been buried by dumps from this and from the company's new quarry on the right bank of the river, about a quarter of a mile further downstream. Upon development of the new quarry, the old upper quarry was abandoned in 1931, and the Moorabool River was diverted through it, since when much of the fine section on the east side has been obscured by slumping. Approximate thicknesses, from above, of this section are:—

(*g*) 6 feet Basalt.
(*f*) 16 feet White sands.
(*e*) 15 feet Brown ferruginous sands.
(*d*) 30 feet Yellow and grey clays and marls, more calcareous towards the base.
(*c*) 30 feet Earthy limestones.
(*b*) 30 feet White bryozoan limestone, weathering yellowish brown, and passing downwards into
(*a*) 45 feet Lepidocycline limestone.

172 feet

The floor of the quarry, now flooded, was below river level, and a shaft sunk below it disclosed a further 50 feet of lepidocycline and bryozoan limestone, towards the base becoming rich in granitic quartz grains derived from the adjacent Dog Rocks granite, which doubtless forms the bedrock. In the new quarry the limestones, which are at least 120 feet thick, are similarly overlain by about 30 feet of clays, here less oxidized and therefore grey in colour, which, like that of the filter quarries, contain a shelly fauna (107, p. 161) similar to that of the Fyansford clay (104, p. 19), with which they are continuous, and which the writer, like Hall and Pritchard, refers to the Balcombian.

The Batesfordian may be defined as the interval of time represented by the deposition of the Lepidocyclina*-bearing limestones of the Batesford quarries, as well as those represented therein by non-deposition or erosion.*

The limestone fauna of the Filter and Upper Quarries has been listed by Hall and Pritchard (104, p. 18; 107, p. 159), and by Chapman (299) in a study of the foraminifera, which were later also studied by Heron-Allen and Earland (324).

The characteristic foraminifera are:—

Lepidocyclina (*Nephrolepidina*) cf. *tournoueri* Lemoine and Douvillé, *L.* (*N.*) *martini* Schlumberger, *L.* (*N.*) *marginata* (Michelotti), *Cycloclypeus communis* Martin, *Operculina victoriensis* Chapman and Parr, *Amphistegina lessonii* d'Orbigny, *Rotalia verriculata* Howchin and Parr, *Gypsina howchini* Chapman. The commonest associated larger fossils are *Phyllacanthus duncani* Chapman and Cudmore and "*Chlamys*" *murrayanus* (Tate).

Cheltenhamian Stage.

Here proposed for the fossiliferous ferruginous sandstones of the lower part of the coastal cliffs and the underlying "nodule bed" at Beaumaris, near Cheltenham, Port Phillip (31, 108).

The "nodule bed" appears above low tide mark on the axis of a gentle anticline immediately north-east of the boatshed and opposite the Hotel. It consists of a 3-inch layer of grit with well rounded clear quartz grains and larger subangular fragments of yellowish reef quartz, together with numerous ferruginous and slightly phosphatic concretions of cylindrical form, up to 5 or 6 inches in length. This nodule bed contains a rich fauna of sharks' teeth, of which *Isurus hastalis* (Agassiz) and *Heterodontus cainozoicus* (Chapman and Pritchard) are among the commonest, together with remains of other fishes and cetacean bones. The worn condition of many of the teeth suggests a remanié origin for some of the fossils, among which invertebrates are rare, though *Placotrochus deltoideus* Duncan, *Magadina* aff. *compta* (Sowerby), and *Zenatiopsis augustata* Tate occasionally occur.

The nodule bed, which marks a stratigraphic break, rests upon an eroded surface of impure limestone or calcareous sandstone, apparently the calcified and hardened upper portion of the Balcombian strata, chiefly marls, which form the sea floor below low tide mark opposite the boatsheds. From limestone pebbles of the beach shingle, derived from this older series, a small faunule (108) has been obtained which includes typical Balcombian mollusca such as "*Cerithium*" *apheles* T. Woods and *Pterospira hannafordi* (McCoy). At its highest point the nodule bed is about 1 foot above beach level, and is overlain by a 2-inch band of *Placunanomia* cf. *ione* (Gray), followed by ferruginous sandstones which are soon obscured by hill wash. Apparent dips of 1° S.S.W. and $1\frac{1}{2}$° N.N.E. soon carry the nodule bed beneath the beach floor, which it occupies, however, between tide marks immediately south-west of the boatshed.

The cliff section (A) opposite the Beaumaris Hotel, at a spot 70 feet south-west of the boatshed and the centre line of Bodley-street, is as follows:—

(ix) 4 feet (?) white sands.
(viii) 6 feet ferruginous sandstone.
(vii) 8 feet ironstones.
(vi) 14 feet ferruginous sandy marl (?).
(v) 9 feet sandy marl with *Lovenia*.
(iv) 6 inches with decomposed shells (*Eucrassatella*, etc.).
(iii) 8 feet marly sands with calcareous concretions.
(ii) 1 foot fine sandy marl, with top 4 inches locally laminated.
(i) 6 inches calcareous sandstone, downward continuation hidden by beach sand.

51 feet.

Bed (i) appears lithologically similar to that *below* the nodule bed north-east of the boatshed, but the resemblance is probably due to secondary calcification, since here the nodule bed, exposed on the beach floor at low tide, must be about 1 foot below the base of the visible cliff section.

Bed (iii) is notable for undulations which, though perhaps in part concretionary, appear to be actual folds, possibly due to "slumping" after deposition. These "folds" are truncated by bed (iv), with very decomposed bivalves, of which the commonest is *Eucrassatella* cf. *camura* (Pritchard), and occasional quartz pebbles up to ¾ inch, also suggesting a break at the base of this bed. The succeeding bed (v) contains abundant *Lovenia forbesi* (T. Woods) and occasional *Monostychia* cf. *australis* Laube. Beds (vi) to (viii) are apparently unfossiliferous, but are largely masked at this spot, so that it is uncertain if (viii) continues to the top of the cliff or if (ix) is present. To the south-west, however, where the cliff top rises, bed (ix) constitutes a capping to the ferruginous beds of about 10 feet of white sands, perhaps Pleistocene, if they are the source of the extinct kangaroo remains which have been recorded from the beach shingle (605).

On the north-east of the boatshed the cliffs for about 300 yards are completely broken down and masked by vegetation, but good cliff sections occur from Ray-street eastwards. At a spot (B) 150 yards east north east of the steps leading to the former baths, a nearly vertical cliff section shows:—

(*d*) 8 feet white sands.
(*c*) 19 feet ferruginous sandstone with hard bands.
(*b*) 17 feet pale fine sandstone or sandy marl.
(*a*) 3 feet brown sandstone with shells near high water mark.

47 feet.

The nodule bed is not exposed, but may be reached by digging for about 2 feet in the beach shingle (108). Bed (*a*) at the base of the cliffs contains a typical shelly fauna, in which

Limopsis beaumariensis Chapman is perhaps the most abundant species. Bed (*b*) contains in its lower part *Neotrigonia acuticostata* (McCoy) and occasional large *Cucullaea praelonga* (Singleton), particularly just past a point (c) about 50 yards further easterly, where bed (*a*) contains hard shelly bands with *Eucrassatella* and *Alturia*.

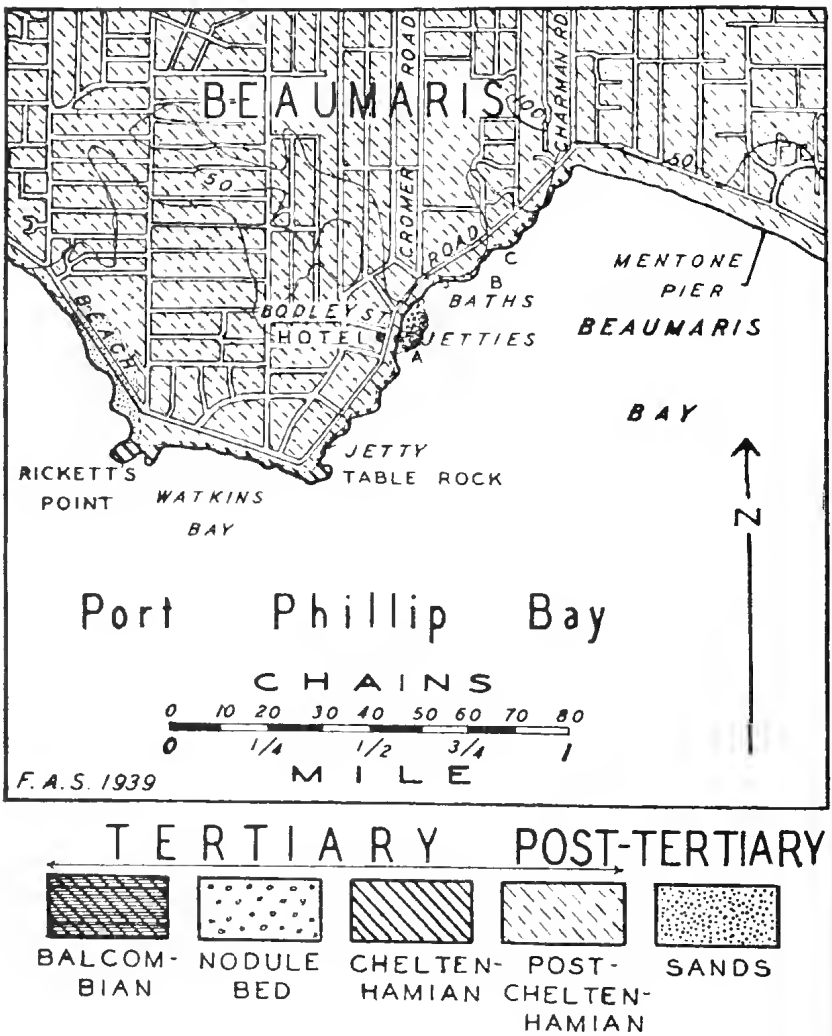


FIG. 6.—Geological map of Beaumaris, Victoria. Contours from Ringwood sheet, Military Survey of Victoria, 1915.

Beds (iii) to (v) of the section west of the boatshed cannot be recognized here, but the succeeding ferruginous sandstones are evidently represented by bed (*c*), and bed (ix) by bed (*d*).

Since bed (*d*) is probably Pleistocene and bed (*c*) may perhaps be Kalimnan or younger, it seems desirable to restrict the Cheltenhamian to the definitely fossiliferous beds beneath them, down to the nodule bed.

The Cheltenhamian may be defined as the interval of time represented by the deposition of the nodule bed and of the overlying sandstones constituting beds (a) and (b) in the above sequence at Beaumaris, near Cheltenham, as well as those represented therein by non-deposition or erosion.

At the type locality the fauna has been listed by Hall and Pritchard (108, pp. 191-197) and also by Dennant and Kitson (275), who did not, however, separate it from that of the strata below the nodule bed. Other names referring to this section are Cheltenham, Moorabbin, and Mordialloc.

Characteristic mollusca include:—

Pelecypoda: *Limopsis beaumariensis* Chapman, *Neotrigonia acuticostata* (McCoy), *Placunanomia* cf. *ione* (Gray).

Eyrian.

This term was first introduced in 1926 by Woolnough and David (652, p. 340) in a vertical stratigraphical section at Muloowurtina, South Australia. In it they show 200 feet of strata, overlying the Winton Series of Upper Cretaceous age, and state "Eyrian Series (Tertiary).—Sandy shales. These contain fossil leaves of *Eucalyptus*, &c., in places." In the legend to the accompanying geological map (652, pl. 22) they add "Eyrian Series. Mesas of 'Desert Sandstone' with grey Shales, fresh-water. Occasional leaves of Banksia, Eucalyptus, &c. Possibly this Series is Cretaceo-Tertiary," though elsewhere (652, p. 349) they describe it as Older Tertiary to Miocene.

It would seem that these authors did not intend to propose a stage name, but only to name a local (even though widespread) series, and it has been used in this sense by E. J. Kenny (32, pp. 85-89), who thought the strata in the West Darling district of New South Wales which he referred to the Eyrian Series might "be assigned to the Lower Tertiary, pre-dating at least partially, if not wholly, the period of accumulation of the Marine Tertiaries of the Murray artesian basin."

David (2, table 1, opp. p. 87), in referring the Eyrian Series provisionally to the Eocene, appears, however, to use it as a subdivisional term comparable to those proposed by Hall and Pritchard for the later marine formations.

The writer (*infra*, p. 51) believes the series may have an extended but perhaps somewhat younger range in time, possibly Oligocene to Miocene, though it must be admitted that the evidence of age is very slender.

It is here suggested that the original usage as the name of a series of strata developed in the Lake Eyre district of South Australia, and not as the name of a stage, be adhered to. The name Eyre Series, comparable with Winton Series, &c., would be preferable to the form Eyrian, but neither term need be further considered here.

Gambierian Stage.

This term was introduced in 1916 by Chapman (57, p. 381), in referring the lower beds of the Mallee bores of North-West Victoria to "Miocene (Janjukian with a Gambierian facies)," which is stated in a footnote to be "Typically represented by the white polyzoal limestone of Mount Gambier, South Australia." This limestone was, however, placed by Hall (103) with the Balcombian of Muddy Creek, Western Victoria, with which beds Tate and Dennant (185) had also associated it.

The name Gambierian was omitted by Chapman from his discussion later in the same paper (57, pp. 409, 411) of the subdivisions of the Tertiary beds, and it seems desirable to follow suit and leave the name in abeyance until such time as it may be proved to be a stage in the Barwonian System not comprehended in either the Balcombian or the Janjukian stage.

Giralian Stage.

Proposed herein for the *Discocyclina* limestones between Giralia and Bullara, near the head of Exmouth Gulf, in the North-West Division of Western Australia (fig. 1). These constitute a thin series, 10-30 (?) feet in thickness, resting with a disconformity upon the Cardabia series (Turonian-Campanian) of the Upper Cretaceous, which latter is exposed by erosion of the eastern limb of the shallow Giralia anticline. Their relationship to the thick *Lepidocyclina* limestones, probably Upper Oligocene to Lower Miocene, of the Cape Range, some 20 miles to the north-west, is as yet unknown.

Since field knowledge (73, 74, 156) of the *Discocyclina* limestones remains virtually restricted to the fact of their occurrence at two localities on the track between Giralia and Bullara, at the northern end of the Giralia Range, and at Red Bluff and Cape Cuvier (78), on the coastline 120 miles to the south-south-west, selection of a type section is not at present desirable.

The Giralian may be defined as the interval of time represented by the deposition of the Discocyclina*-bearing limestones of North-Western Australia, as developed between Bullara and Giralia, as well as those represented therein by non-deposition or erosion.*

The foraminifera of the two localities in the Bullara area have been determined by Chapman and Crespin (306), from whose

identifications the following may be selected as characteristic: *Pellatispira orbitoidea* (Provale), *P. inflata* Umbgrove, *Discocyclina pratti* (Michelin), *D. dispansa minor* Rutten, *Asterocyclina* cf. *stellata* (d'Archiac), and *Nummulites* sp., the last being recorded only from the second locality, and *Asterocyclina* only from the first.

Hamiltonian.

A term used in 1922 by Mawson and Chapman (640, p. 146) in the form Hamiltonian facies, defined in a footnote as "A regional word, here coined to express the combined faunas of the lower and upper Muddy Creek beds with the intercalated limestone of the Grange Burn, ranging from the Balcombian to the Kalimnan."

But the Grange Burn limestone with lepidocyclinae (at that time referred by Chapman to the Janjukian, but by the present writer to the Batesfordian), instead of being intercalated, is actually antecedent to the lower beds (Balcombian of Clifton Bank) at Muddy Creek, as originally maintained by Dennant (83) and since proved by the Muddy Creek bore. The term Hamiltonian can only be used for a system comprising (in terms of the present writer's views as to sequence) the Batesfordian, Balcombian, and Kalimnan stages. It thus overlaps the earlier proposed and better known Barwonian system, and is only a comprehensive term for the whole of the marine Tertiary strata of the Hamilton district, which are referable to stages already defined.

It is therefore suggested that the name Hamiltonian is unnecessary and should be abandoned, as has been done, indeed, by Chapman himself.

Janjukian Stage.

This, probably the most important stage in point of size, was introduced by Hall and Pritchard (112, pp. 78, 79) in 1902, with slightly different spelling, as follows:—"Jan Jucian.—The section near Spring Creek, on the coast of Bass Strait, south of Geelong, is in the main in the Parish of Jan Juc, and its fauna differs greatly from that of Balcombe's Bay. . . . The township near Spring Creek is called Torquay, but the use of this name in England renders another advisable. The older name for Torquay was Puebla, but the employment of this name, again, would lead to confusion with certain American strata. The name Jan Juc remains, and is referred to by McCoy as the locality whence several of his fossils came."

The coastal section referred to by Hall and Pritchard extends along Half Moon Bay, in the Parish of Jan Juc, for about 3 miles south-westerly from a point immediately south of Torquay, a township 13 miles south of Geelong, Victoria. The strata form

a broad half-dome whose centre is a few yards south-west of the rock stack known as Bird Rock, from which the lower beds, with a rich molluscan fauna, outcrop near the base of the cliffs opposite, known as Bird Rock cliffs, as far as Fisherman's Steps, about a mile to the south-west.

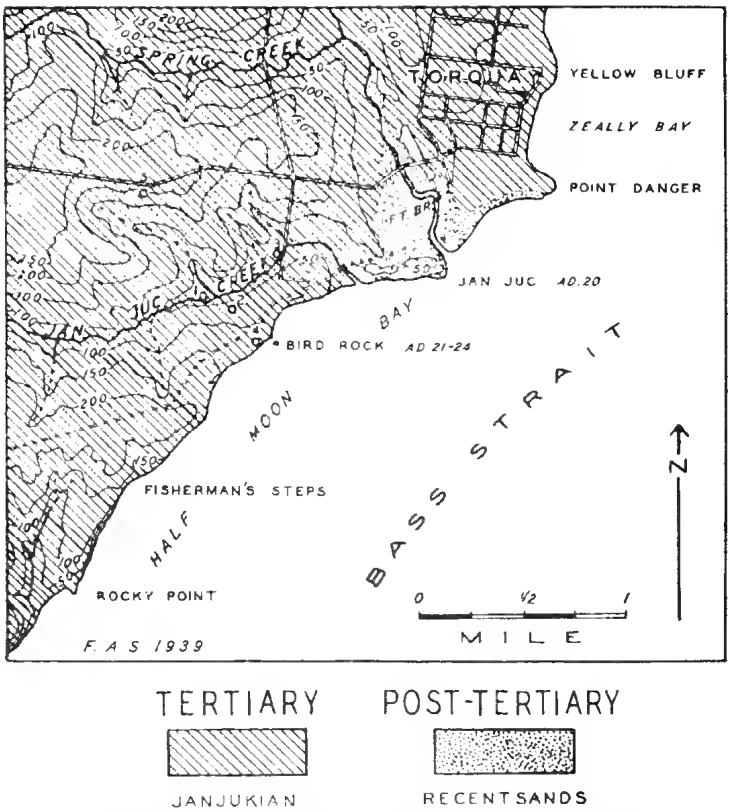


FIG. 7.—Geological map of Torquay District, Victoria. Modified in part from Quarter-sheet No. 2S S.E., Geological Survey of Victoria, 1863. Contours from Anglesea sheet, Military Survey of Victoria, 1915.

On either limb of the fold the upper beds, chiefly bryozoan limestones with echinoids, &c., are brought down towards beach level by low dips of about 4°–6°, and form on the north-east the cliffs between Bird Rock and the mouth of Spring Creek, and on the south-west those between Fisherman's Steps and Rocky Point, along which cliffs the impure limestones ("echinoderm-rock") are overlain by a younger series of shelly clays.

A good account of the section has been given by Tate and Dennant (183, p. 206; 184, p. 118), who recognized only a division into upper and lower beds, the former including both

limestones and upper clays, and the latter the richly fossiliferous sandy clays and marls, often glauconitic, at or near the horizon of Bird Rock. This was accepted by Hall and Pritchard (107, p. 156), though Daintree, who had first made a twofold division (28), later adopted a threefold division (marginal notes to quarter-sheet 28 S.E., Geological Survey of Victoria, by Daintree and Wilkinson, 1863). More recently Chapman and Singleton (27, p. 994) have described the sequence of the upper beds, and also those in deep borings (27, p. 996), while Pritchard (155, p. 935) has proposed on palaeontological grounds seven sets of beds. Of these, the present writer identifies the Scutellina Limestones as those of the point and rock stack, immediately south of the mouth of Spring Creek, marked on the military survey map as Jan Juc, a name given on quarter-sheet 28 S.E. to the first point north-east of the mouth of Spring Creek, now known as Point Danger, and the Cellepora Limestones as those of the cliffs between the mouth of Jan Juc Creek and Bird Rock. Descending stratigraphically, the Ancilla Clays and the Septarian Limestones apparently belong to the upper part of the cliff section, about 180 feet in height, opposite Bird Rock; the Chione clays are regarded as the richly fossiliferous glauconitic clays *above* the hard band which caps Bird Rock; and the Glycymeris beds and the Limopsis beds as the sandy marls *below* the same hard band, which Hall and Pritchard identified (107, p. 155) as that dividing Daintree's upper and lower beds. The greater part of the fossils listed from the locality, which has variously been termed Spring Creek, Bird Rock Bluff, and Torquay, come from the last three of Pritchard's subdivisions.

Since it is hoped in the near future to furnish a detailed account of the stratigraphy and successive faunules of this important section, it is advisable for the present to define the stage in somewhat general terms. It is unfortunate that the cores of the deep borings made by the Torquay Oil Wells Company are unavailable for examination, but an earlier shallow bore reported on by Chapman (267) proved a downward extension of the lower beds of the Bird Rock Cliffs for 70 feet, while Chapman and Singleton (27, p. 996) stated similar greensands and marls to occur at 170 feet below sea level, and it seems reasonable to extend the Janjukian downward to this depth. Pritchard (155, p. 936) claimed a total thickness (inclusive of 183 feet in outcrops) of rather more than 1,000 feet for the marine series, but since lignitiferous sands with *Cyclammina* (here referred to the Anglesean) were reported between 840 and 410 feet below sea level (27, p. 996), much of this cannot be regarded as Janjukian.

The Janjukian may be defined as the interval of time represented by the deposition of the marine beds outcropping in the coastal sections, about 3 miles in length, between Rocky Point

and the mouth of Spring Creek, in the Parish of Jan Juc, and proved in borings to a depth of 170 *feet below sea level, as well as those represented therein by non-deposition or erosion.*

The fauna of the type locality, under the name of Spring Creek, but without subdivision into upper and lower beds, has been listed by Tate and Dennant (183) and by Dennant and Kitson (275). The fossils from the limestones of the upper beds have been recorded by Hall and Pritchard (107, p. 162) and those of the upper clays by the same authors (107, p. 163) and by Tate and Dennant (183, p. 210; 184, p. 119).

The characteristic mollusca of the lower beds (below the summit of Bird Rock) include:—

Pelecypoda: *Limopsis chapmani* Singleton, *Glycymeris* (*Grandaxinaea*) *ornithopetra* Chapman and Singleton, *Eotrigonia semiundulata* (Jenkins), *Venericardia janjukiensis* Chapman and Singleton.

Gasteropoda: *Volutospina anticingulata* (McCoy), *Polinices wintlei* (T. Woods).

Less common but apparently restricted species include:—

Gasteropoda: *Umbilia platyrhyncha* (McCoy), *Pterospira macroptera* (McCoy), *Bellophos woodsii* (Tate).

Cephalopoda: *Spirulirostra curta* Tate.

Kalimnan Stage.

This was proposed by Hall and Pritchard (112, p. 78) in 1902 as follows: "Kalimnan.—The beds at Jimmy's Point, near the mouth of the Gippsland Lakes, are near the township of Kalimna. They were referred to Older Pliocene by Sir F. McCoy, and by Mr. Dennant to Miocene."

The sandy clays and associated shell beds of the type locality, Jimmy's or Jemmy's Point, also referred to as Kalimna, in Eastern Victoria, have been briefly touched upon by Dennant (85) and by Dennant and Clark (90), but hitherto have not been described in detail. A natural section, not more than 10 feet in height, is given by the low cliffs which extend from Kalimna Hotel jetty eastwards for three-quarters of a mile past Jemmy's Point to the bridge which connects the latter with Lakes Entrance township.

The sequence of the strata at Jemmy's Point is well shown by the cuttings along the road which joins this bridge across the North Arm with the township of Kalimna. In stratigraphic order from above downwards it is as follows:—

(*m*) 20 + feet light grey and reddish sands.
(*l*) 30 feet reddish brown clayey sands, with stratification and sporadic pebbles.
(*k*) 4 inches pebble band, discontinuous, including rhyolite pebbles.
(*j*) 8 inches carbonaceous layers in fine sandstone.
(*i*) 3 feet foraminiferal silt.

(*h*) 1 foot upper shell bed, somewhat irregular and thinning out to W.
(*g*) 1 foot 6 inches hard laminated sandstone.
(*f*) 13 feet sandy marls with concretionary bands.
(*e*) 4 inches hard band.
(*d*) 13 feet sandy marl and concretionary sandstones.
(*c*) 2 feet lower shell bed, sandy marl with *Eucrassatella*, etc.
(*b*) 2 feet 6 inches concretionary sandstone with a few *Turritella* near top.
(*a*) 3 feet 6 inches fine sandstone to base of section, about 2 feet above high water mark.

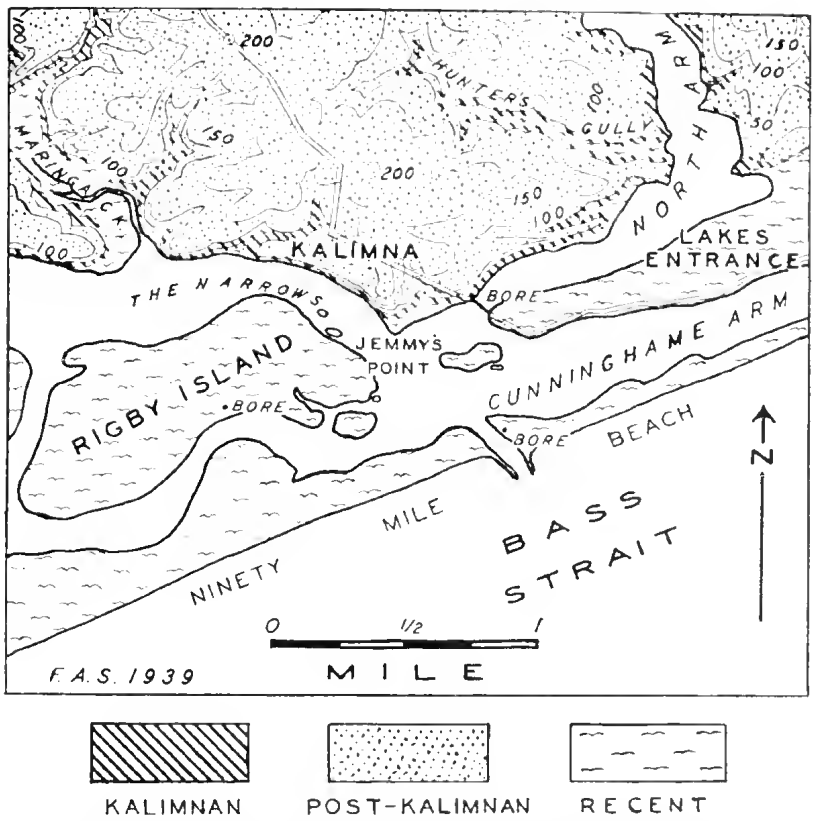


FIG. 8.—Geological map of Kalimna district, East Gippsland, Victoria. Modified from geologically coloured and contoured parish plan of Colquhoun. Geological Survey of Victoria, 1929.

Pebbles, though very rarely present in the upper shell bed (*h*), are common on the unfossiliferous beds which succeed the silt bed (*i*), in which W. J. Parr has recognized abundant *Nonion victoriense* (personal communication), and which is here taken as the upward limit of the Kalimnan at this locality. Beds (*j*)–(*m*) are therefore believed to be an Upper Pliocene or Pleistocene series, probably non-marine, resting disconformably on the Kalimnan strata (*a*)–(*i*). Macro-fossils are almost

entirely confined to the shell beds (*c*) and (*h*) and to the upper part of (*b*), but are known to occur in depth in No. 1 Government Bore, Parish of Colquhoun (No. 3, Lakes Entrance), situated at about 9 feet above high water mark, near the north-western end of the bridge. This bore (25, p. 13; 38, p. 89) showed the Kalimnan strata to persist, with a rich fossil zone about 10 feet thick, first met with at 90 feet, down to a depth of 140 feet, being underlain by pre-Kalimnan Tertiary strata till the granitic bedrock is reached at 1,404 feet.

It is reasonable to add to the exposed Kalimnan strata (*a*)–(*i*), totalling 40 feet, a further 133 feet proved in the bore, giving a total of 173 feet of Kalimnan beds at the type locality.

The Kalimnan may be defined as the interval of time represented by the deposition of the sandy marls and sandstones constituting beds (a)–(i) in the above sequence at Jemmy's Point, Kalimna, together with similar beds down to 131 *feet below sea level, proved by boring at this locality, as well as those represented in the preceding by non-deposition or erosion.*

At the type locality the foraminifera have been identified by Parr (339), and the mollusca and a few other groups listed by Dennant (85), with subsequent alterations and additions (90). The records by Dennant and Kitson (275) are not confined to Jemmy's Point, in the fauna of which there remains a substantial undescribed residue.

Characteristic species of foraminifera, which occur throughout the outcropping beds, are *Glandulina kalimnensis* Parr, *Planulina kalimnensis* Parr, *Nonion victoriense* Cushman, *Flintina intermedia* (Howchin).

The characteristic mollusca of the lower shell bed (*c*) are:—

Pelecypoda: *Cucullaea praelonga* (Singleton), *Glycymeris* (*Veletuceta*) *paucicostata* Pritchard, *Ostrea arenicola* Tate, *Neotrigonia howitti* (McCoy), *Chlamys asperrimus antiaustralis* (Tate), *Anomia tatei* Chapman and Singleton, *Venericardia trigonalis* (Tate), *Encrassatella kingicoloides* (Pritchard), *Clausinella* (*Placamen*) *subroborata* (Tate), *Notocallista* (*Striacallista*) *submultistriata* (Tate), *Bassina paucirugata* (Tate).

Gasteropoda: *Turritella* (*Colpospira*) *conspicabilis* Tate, *Tylospira coronata* (Tate), *Polinices* (*Conuber*) *cunninghamensis* (Harris), *Merica wannonensis* (Tate), *Nassarius crassigranosus* (Tate).

In the upper shell bed (*h*) the characteristic mollusca are:—

Pelecypoda: *Nucula* (*Ennucula*) *kalimnae* Singleton, *Nuculana* (*Scaeoleda*) *crassa* (Hinds), *Glycymeris* (*Veletuceta*) *paucicostata* Pritchard, *Neotrigonia howitti* (McCoy), *Clausinella* (*Placamen*) *subroborata* (Tate), *Aloidis* (*Notocorbula*) *coxi* Pilsbry.

Gasteropoda: *Bankivia howitti* Pritchard, *Leiopyrga quadricingulata* Tate, *Polinices* (*Conuber*) *cunninghamensis* (Harris), *Merica wannonensis* (Tate), *Nassarius crassigranosus* Tate.

Murravian Stage or System.

The first use of the term Murravian appears to have been in 1878 by Tate (171, p. 123), who listed the corals of the River Murray cliffs under the heading "Upper Murravian Series." He used the term in the sense of a local series rather than as a stage name, and on the preceding page referred to "the middle and lower Murray series." He also gave a generalized section of the strata of the River Murray cliffs, as follows (171, p. 121):—

"1. Lacustrine (?) sand and marls. No fossils, exceeding 60 feet in thickness.

2. Upper Marine Series; shelly limestones (false bedded) and oyster beds, with occasional argillaceous and sandy beds. Rich in gasteropods and corals. About 50 feet thick.

3. Middle Marine Series; usually a yellow calciferous sandstone; 40–45 feet thick. Rich in echinoderms, brachiopods, pectens, and polyzoa.

4. Lower Marine Series; Ferruginous sandstones and polyzoan limestones. Rich in echinoderms and brachiopods, but for the most part of different species to those in the upper beds."

In the following year, Tate repeated this subdivision in a correlation table (47, p. liii):—

"Upper Murravian. Shell limestones, oyster beds, and sands.
Middle Murravian. Calciferous sandstone with polyzoa.
Lower Murravian. Ferruginous sandstone and polyzoal limestone."

Finally, in 1885, Tate (175) discussed fully the stratigraphy of the Murray River cliffs, illustrated by measured vertical sections at three localities: near Glenforslan, 4 miles north from Blanchetown; at North-West Bend Head Station; and at 4 miles south from Morgan. The Upper Murravian was restricted to the oyster banks (characterized by *Ostrea sturtiana* Tate), the underlying beds, with a rich gasteropod fauna at the locality 4 miles south of Morgan, being transferred to the Middle Murravian. Of the Lower Murravian, which is exposed only at the first of the above sections, he remarked (175, p. 41):—"This series is characterized rather by lithological than by palaeontological characters, which latter are somewhat negative, as the species are few in number and somewhat sparsely distributed. It is often highly charged with gypsum, and then fossils are rarely present."

The upper beds, whose fossils are usually poorly preserved, largely as casts, rest in places upon an eroded surface of the middle beds, as at North-West Bend (185, p. 119). These

middle beds, at all events the shelly clays at the locality 4 miles below Morgan, the writer provisionally places in the Balcombian, a correlation previously implied by Tate (181), though they were referred by Chapman (57, p. 411) to the Janjukian. The unconformably overlying upper or oyster beds have nearly always been placed (44, 57, 112, 185) in the Kalimnan, but the evidence is by no means conclusive and the beds may well be somewhat older.

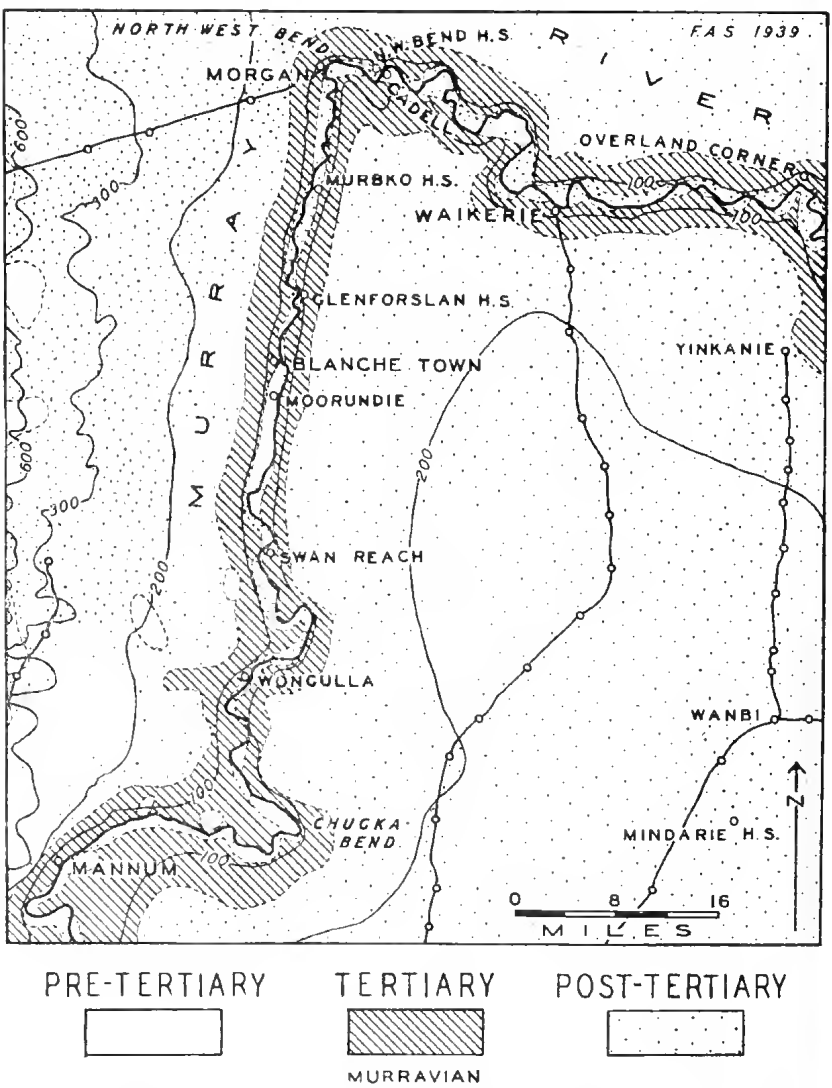


FIG. 9.—Geological map of part of the Murray River basin, South Australia. Modified from maps of the South Australian Departments of Lands and Mines. Contours modified from Adelaide sheet, International Map of the World 1: 1,000,000, and railway heights.

The term Murravian was not considered by Hall and Pritchard (112) in their discussion on nomenclature, and the writer is opposed to its use as a stage or system name for reasons similar to those advanced in respect to the Hamiltonian. Since its use in the form Murravian series has recently been revived by E. J. Kenny (32, p. 93), it is desirable to give a more precise definition. It is difficult to select a single type locality, since at the section 4 miles below Morgan, from which Tate obtained nearly all his fossils, his Lower Murravian is not present, and at other sections where it occurs all the strata are poorly fossiliferous. The definition must therefore be in somewhat general terms.

The Murravian may be defined as the interval of time represented by the deposition of the marine beds outcropping in the River Murray Cliffs between Blanchetown and North-West Bend, South Australia, as well as those represented therein by non-deposition and erosion.

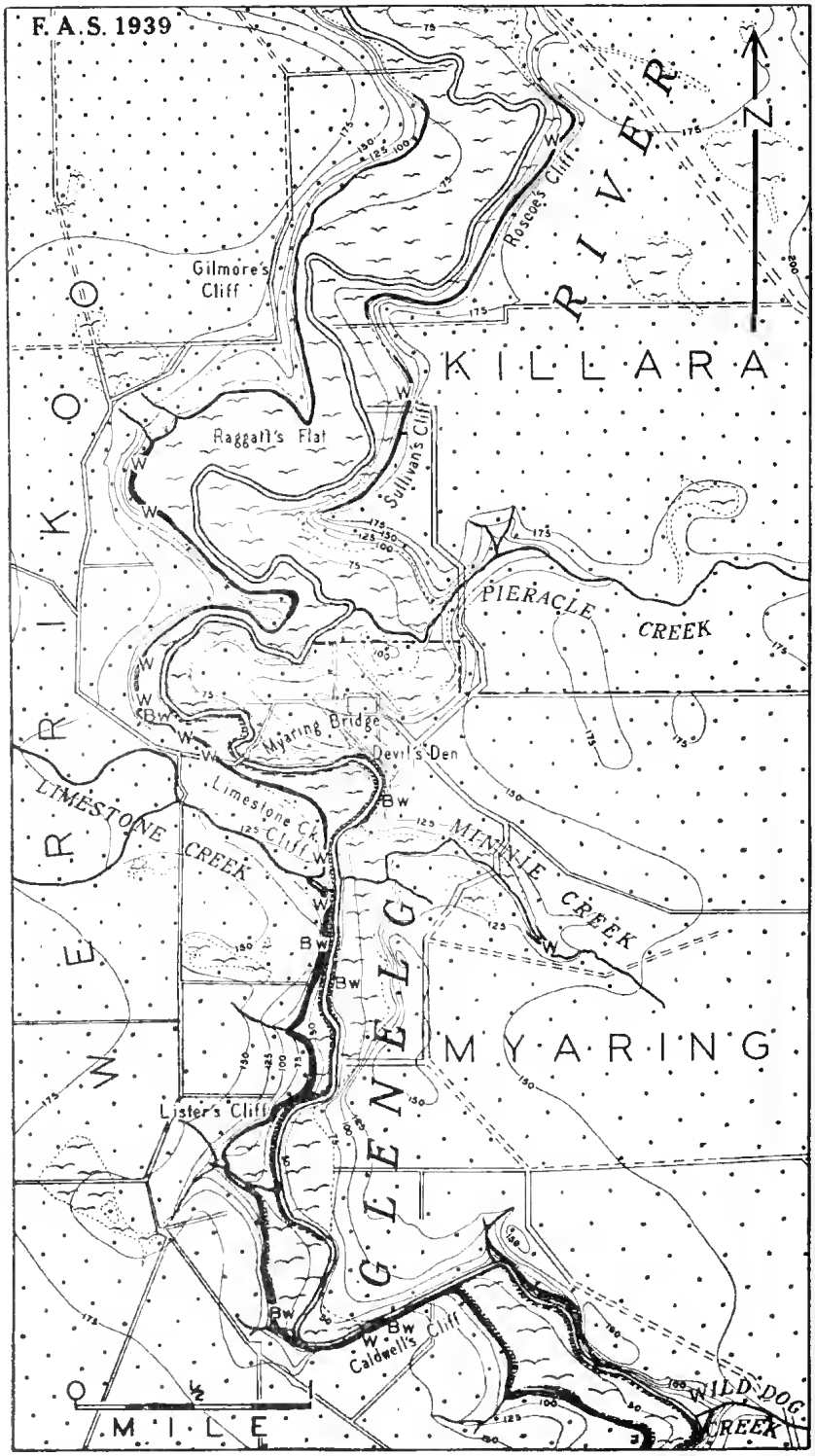
The fauna has been listed by Tate, and the species of the three divisions discussed (175, pp 35-41), while Dennant and Kitson (275) have not distinguished between those of the two lower divisions.

Werrikooian Stage.

Defined in 1902 by Hall and Pritchard (112, p. 77) as follows:—"Werrikooian. The Limestone Creek beds on the Glenelg River are in the Parish of Werrikoo, in the County of Follett. They have been referred to Pleistocene and to Pliocene. There is another Limestone Creek, near the head of the Murray, in Victoria, which yields Palaeozoic fossils, and a third in the County of Heytesbury, with Older Tertiary fossils."

These beds were first described, under the name Bankivia Beds, by Dennant (82, 84), who regarded them as deposited in a former estuary of the Glenelg River, cut through the Ostrea Limestone and the underlying "coralline" [i.e., bryozoan] limestone of Older Tertiary age. The writer (44, 159) has since shown that at the section on the right bank of the Glenelg River in allotment 68, Parish of Werrikoo, known as Caldwell's Cliff, the Werrikooian shell bed rests unconformably on Barwonian bryozoan limestone and is itself conformably overlain by sandy limestones which are capped by the Ostrea Limestone.

The localities visited by Dennant occur in the Glenelg River valley in the Parishes of Werrikoo, Killara, and Myaring, and extend from the junction of Limestone Creek to Roscoe's Cliff, in the Parish of Killara, about 3½ miles to the north. At none of them is the shell bed satisfactorily developed *in situ*, so that as a type locality Caldwell's Cliff, nearly 2 miles south of the junction, is here selected.



BARWONIAN WERRIKOOIAN PLEISTOCENE RECENT

FIG. 10.—Geological map of the Glenelg River valley near Limestone Creek, South-Western Victoria. Modified from geologically coloured and contoured parish plans of Killara, Myaring, and Werrikoo, Geological Survey of Victoria, 1937-8, with additions. Bw, Barwonian fossils. W, Werrikooian fossils.

[*Page 46.*]

At this locality, first discovered by J. J. Caldwell of the Geological Survey of Victoria, the sequence measured by the writer is as follows:—

(*m*) 4 feet sandy soil.
(*l*) 2 feet 4 inches oyster bed with *Pecten (Notovola) meridionalis.*
(*k*) 10 feet 6 inches laminated and cross-bedded limestone with sporadic oysters.
(*j*) 6 feet limestone with abundant irregular concretions.
(*i*) 3 feet 4 inches flaggy limestone.
(*h*) 6 inches oyster band with *Equichlamys bifrons* and mould of *Dosinia.*
(*g*) 1 foot 6 inches limestone.
(*f*) 8 inches oyster band with quartz pebbles.
(*e*) 3 feet limestone.
(*d*) 6 inches oyster band with *Placunanomia,* locally with a 2-inch clayey capping.
(*c*) 8 feet limestone with sporadic oysters and other bivalves (*Placunanomia, Glycymeris*), chiefly in a 4-inch grit band 2 feet above its base.
(*b*) 1 foot shell bed, resting unconformably on
(*a*) 53 feet bryozoan limestone, largely masked by slip material.

The top 3 inches of bed (*a*), of Barwonian age, is bored by *Barnea,* casts of which may be found *in situ.* Bed (*b*), which contains the typical Werrikooian fauna, differs in appearance from the sparsely fossiliferous limestones (*c*)–(*h*) which follow, but the relation is one of conformity, and the same apparently applies to the succeeding beds up to (*l*), which is the well-marked Oyster Bed of the district. This latter is referable to the Ostrea Limestone of Dennant (84), but whether beds (*i*)–(*k*) should be included also is debatable.

Shell bed (*b*), containing a fauna of 200 mollusean species, with about 5 per cent. of extinct species and an extinct genus, is referred by the writer to the summit of the Pliocene, and the succeeding strata may well bridge the boundary of the Pleistocene. For field mapping it is probably best to assume that the beginning of the Pleistocene is marked by the incoming of *Pecten (Notovola) meridionalis* Tate. Provisionally beds (*c*)–(*i*) may be referred to the Werrikooian and beds (*j*) (*l*) to the conformably succeeding Pleistocene.

The Werrikooian may be defined as the interval of time represented by the deposition of the shell bed and sandy limestones constituting beds (b)–(i) in the above sequence at Caldwell's Cliff, Glenelg River, in the Parish of Werrikoo, as well as those represented therein by non-deposition or erosion.

The fauna at the type locality as above defined has been studied by the writer, but results are not yet published. The original lists given by Dennant (82, 84), based on identifications by Tate, and the slightly amended list of Dennant and Kitson (275), all need considerable revision, not only in nomenclature but also because they include a number of extinct species actually derived from the underlying Barwonian (? Balcombian) marls, which outcrop near river level at several localities.

Some of the characteristic molluscan species are as yet undescribed, but the remainder include:—

Pelecypoda: *Nucula* (*Ennucula*) *kalimnae* Singleton, *Nuculana* (*Scaeoleda*) *crassa* (Hinds), *Glycymeris* (*Veletuceta*) cf. *striatularis* (Lamarck), *Chlamys asperrimus dennanti* Gatliff and Singleton, *Zenatiopsis angustata* Tate, *Clausinella* (*Placamen*) *placida* (Hanley).

Gasteropoda: *Bankivia fasciata* (Menke), *Turritella* (*Ctenocolpus*) *terebellata* Tate, *Polinices conicus* (Lamarck).

On the left bank of the Glenelg River at Dartmoor, immediately south of the railway, the following section recalls lithologically the upper part of Caldwell's Cliff:—

(*d*) 14 feet false bedded and thinly laminated limestone, with *Pecten meridionalis* at 5 and 7 feet above base.
(*c*) 5 feet irregularly nodular limestone, with a few oysters at the top.
(*b*) 8 inches oyster bed with *Pecten meridionalis* and *Placunanomia*.
(*a*) 12 feet flaggy limestones, downward extension obscured by talus down to rail level

At both localities the general sequence is similar and the beds appear to be beach or dune deposits, with a marine incursion represented by the oyster bed. This latter, characterized by an oyster which is probably a new subspecies of *Ostrea sinuata* Lamarck, does not occupy the same position in the Dartmoor section, of which beds (*b*)–(*d*) must be referred to the Lower Pleistocene on the criterion suggested above. Since the lower part of the section is obscured by talus, it is uncertain if bed (*a*) is underlain by the Werrikooian shell bed.

Yallournian.

This term was introduced in 1935 by the writer (17, p. 128 and footnote), with the brief statement "Proposed for the lignites and clays of Yallourn."

At Yallourn, in the Parish of Narracan, Gippsland, Victoria, the State Electricity Commission's open cut has exposed 200 feet of lignite overlain by 30 feet of freshwater clays capped by sands.

A deep boring nearby, No. 471, Parish of Narracan (38, p. 144), shows:—

20 feet clay and sand.
237 feet brown coal.
1 foot ligneous clay.
5 feet brown coal.
4 feet ligneous clay.
8 feet brown coal.
48 feet clay.
48 feet brown coal.
20 feet clay.

436 feet depth bored from surface level at 128 feet.

Since, for purposes of correlation, stage names should preferably be based on marine formations, the same objections apply to the Yallournian as to Eyrian, to which, indeed, it may be partially equivalent in time. It is therefore best regarded as a series, preferably in the form Yallourn Series, and not as a stage name.

Non-Marine Deposits.

For reasons already indicated the non-marine Tertiary deposits can be discussed in only a very approximate chronological order. The following allocations are thus tentative.

Eocene.

Amongst the earliest non-marine deposits, if indeed they are Tertiary, are the unfossiliferous grey shales, sandy clays and sands, apparently of fresh-water origin, reported between 780 and 1,950 feet in King's Park Bore No. 2, near Perth, by Parr (338), who has referred the overlying series, more than 500 feet in thickness, of foraminiferal shales and intercalated sandstones, to the Upper Eocene. But at depths between 1,650 and 1,750 feet in other borings in the Perth area, Miss Crespin has found foraminifera referred to the Lower Cretaceous (338, p. 71), so that while the fresh-water deposits of the King's Park bore are not younger than Upper Eocene, their Tertiary age is not fully established.

Oligocene.

Either Oligocene, or older, are the leaf-bearing pipe-clays of Berwick (238, 240, 636), Narracan (235, 254, 644, 652*a*), and Pascoe Vale (253, 623), which underlie the basalts of the older volcanic series of Victoria, since the basalt of Pascoe Vale may be traced to Royal Park, where littoral marine beds of probably Balcombian age rest on its eroded surface (108, 158). Doubtfully to be placed with them are the "deep leads" (buried fluviatile deposits) of Welcome Rush (45,650) near Stawell, and of the Upper Moorabool River (106, 647) in Victoria, both overlain by marine strata, in the latter case the lower Maude beds of Janjukian age.

Probably Oligocene in the main are the important deposits of lignite or brown coal which, in South Australia and more particularly in Victoria, appear to be pre-Barwonian or else contemporary with the earliest marine stages, probably Anglesean. With their associated sands and clays they have been called by the author Yallournian (17), from their development in Gippsland at Yallourn (624) and elsewhere in the Latrobe Valley, in which seams exceeding 500 feet constitute the thickest perhaps in the world.

From their upper part at Yallourn is a florule (245), in which *Banksia* is dominant, occurring sporadically in the lignites, which otherwise contain no plant remains except coniferous wood (200, 202). To the east these beds appear correlable, in their lower portion at least, with the lignites and clays of the deep borings in the Lake Wellington and Lake Victoria district of East Gippsland (Fig. 15), which are overlain by the Barwonian marine beds of the East Gippsland region, whose earliest part is above referred to basal Miocene or late Oligocene. Sussmilch (18) has urged that such great total thicknesses of lignite, of the order of 800 feet, indicate that the Yallournian must cover an extended period of time, in his view up to the Lower Pliocene. While there is force in his argument that all the lignites are not of the same age, and there is evidence of interdigitation of lignites and ligneous clays with marine beds in bore No. 2, Parish of Nuntin (41), bore No. 1, Parish of Goon Nure (40) and bore No. 1, Parish of Boole Poole (41), these latter are probably Anglesean, and it is likely that the bulk of the Yallourn series is pre-Miocene, as are probably the lignites, sands and clays of Altona (23, 108, 638, 648) and Parwan (38), to the north-west of Port Phillip, which are overlain by marine Balcombian, and those of Moorlands (613, 640) in South Australia, overlain by marine Barwonian strata.

Approximately equivalent to them in age are the clays and sands at the base of the Point Addis bores (38, p. 17), and bores at Dartmoor (38, p. 91) on the Glenelg River, in Victoria, and the carbonaceous sands and pipe-clays of Maslin's Bay near Aldinga, in South Australia, in which plant remains occur (236).

Perhaps to be correlated with the Altona lignitic series are the sands, clays, and impure lignite of the Balcombe Bay bore (36, p. 30), likewise overlain by marine Balcombian, but here underlain by basalt.

The age of beds containing the so-called "*Cinnamomum* flora," but which do not come into relation with marine deposits, cannot always be established. Those of Narracan (235, 254, 644) underlying the "Older Basalt" have above been referred to the Oligocene, and with them may be placed the Elsmore and Vegetable Creek (Emmaville) leads (18, 246), also sub-basaltic, of northern New South Wales, and across the Queensland border the Redbank Plains series (633) near Oxley and Darra, with fish-remains which have been regarded as Oligocene (585). Since the Silkstone series (633) of S.E. Queensland, with shales, sandstones, Planorbis limestones, and contemporary basalts, conformably succeeds the Redbank Plains series, it may likewise be provisionally referred to the Oligocene (616).

As elsewhere suggested by the author (17), the *Cinnamomum* flora probably extends, at least in Victoria, from Oligocene to

Upper Miocene, and Sussmilch's view (18) that it, and indeed all the plant-bearing beds, may be referred to the Lower Pliocene, appears untenable (645, 663).

Miocene.

The Eyrian series of lacustrine sandstones and shales, unconformably overlying the Upper Cretaceous Winton series, is typically developed in the vicinity of Lake Eyre in South Australia, but extends into Queensland. Though originally regarded by Woolnough and David (652, p. 349) as "Older Tertiary to Miocene," David later (2) transferred it provisionally to the Eocene. These Eyrian strata in places contain leaves, including *Eucalyptus* and *Cinnamomum*, and Chapman (237) has referred many localities to the lower Oligocene. They may, however, even be Miocene, and it is likely that the Eyrian (or Eyre series) has an extended range in time, perhaps from Oligocene to Miocene, or even later.

The plant-bearing beds (622) and "deep leads" (29, 232, 628) of Eastern Australia probably cover a similar range, but provisionally to be placed in the Miocene are the quartzites with *Cinnamomum* of Dalton (18, 246), near Gunning, and the leaf beds of the Warrumbungle Mts. (244) and of the Darling Plains (237) in New South Wales; the sands, clays, and ironstones (28) with *Cinnamomum* which overlie "Older Basalt" at Bacchus Marsh, Victoria; and perhaps the leaf beds of Macquarie Harbour in Tasmania. It must be admitted, however, that the flora shows much resemblance to that of localities such as Narracan, which are above included as Oligocene. Certainly not older than Miocene are the pipe-clays of Sentinel Rock (50, 110) on the Aire coast in Victoria, which overlie marine Barwonian beds and contain a distinctive flora in which *Coprosmaephyllum* and *Persoonia* are common (195, 238, 243).

Elsewhere evidence of age is seldom definite, though occasionally leaf remains are entombed in marine deposits, such as the Plantagenet beds of Cape Riche (271) in Western Australia, and the upper or *Turritella* beds near Table Cape (6, p. 242; 250), Tasmania, both probably lower Miocene, and the upper beds at Beaumaris (17), Victoria, with a latest occurrence of *Cinnamomum* in probably Upper Miocene strata.

In Western Australia non-marine strata attributable to some part of Tertiary time include the lacustrine clays and basal grits and conglomerates (7), totalling at least 100 feet in thickness, which rest unconformably on the Permo-Carboniferous coal measures of the Collie River, in the South-West Division, and are in turn overlain by gritty laterite.

Of Tertiary age, perhaps Miocene or Oligocene, are lacustrine deposits of numerous areas in Eastern Queensland (2, 20), including those of the Baffle Creek basin near Port Curtis and of Duaringa in the Dawson valley, and the lignites of Water Park Creek, north of Rockhampton.

Pliocene.

Perhaps referable here are the newer deep leads (27, 195) of S.E. Australia and Tasmania (6), in part covered by the newer volcanic rocks and sometimes containing leaves or fruits, as at Haddon (212, 663) in Victoria, Gulgong (18, 206) in New South Wales, and Brandy Creek (210) in Tasmania. Similar in age may be lacustrine deposits of the Derwent (631, 632) and Launceston (629, 630) basins in Tasmania, while in Victoria the "torrent gravels" of East Gippsland (617, 694) are probably late Pliocene and the result of the initiation of uplift in the Eastern Highlands.

Though the *Planorbis* limestones of Mt. Elder Range (7), in the Kimberley region of Western Australia, have been referred to the Pleistocene (619), their physiographic setting suggests a Pliocene age.

In Central Australia the Arltungan (preferably Arltunga) series (639), perhaps late Tertiary to Pleistocene, consists of sands, clays, and gravels, usually as small mesas, often with chalcedonized "duricrust." The series includes *Planorbis* limestone on Paddy's Hole Plain, and limestones with *Corbicula* on the Hale Plain near Claraville, both in the Arltunga district of the Eastern Macdonell Ranges.

Over much of the interior of the continent silicified or otherwise indurated superficial deposits, which have been termed "duricrust" (705), belong to some part of Tertiary time. Somewhat similar, in Eastern Australia, are the silicified sands or "grey billy" (645) of ancient river deposits, perhaps Pliocene, whose silicification is commonly ascribed to overlying basalt, as at Keilor (108) in Victoria, Tallong, Ulladulla and Moruya (614) in New South Wales, and at Bald Hills in S.E. Queensland, where quartzites occur in the Petrie series (633), chiefly quartzite breccias and micaceous sandstones of late Tertiary age.

Tentatively to the Pliocene have been ascribed some of the deep soils, including "red earths" and "red loams," of Queensland (616), and some of the plateau soils of New South Wales (615) may be similar in age. The older alluvia, sometimes with extinct marsupials, may range back into the late Pliocene, though the majority are more probably Pleistocene.

Igneous Rocks.

In Eastern Australia an earlier volcanic series, chiefly basic, which is developed in south-central Victoria, in north-western Tasmania, in northern New South Wales, and in south-eastern Queensland, is probably chiefly Oligocene, with some members of Lower Miocene age.

In Victoria the Older Volcanic series ("Older Basalts"), which at Western Port is more than 1,000 feet in thickness, includes (661) olivine-basalts, olivine-titanaugite-basalts, and crinanites, as well as some limburgites and nephelinites, all of which are also represented in the associated dyke-swarms, together with camptonites and other lamprophyric types. The "Older Basalts" are overlain unconformably by marine Barwonian sediments, chiefly Lower Miocene, which include Janjukian limestone at Airey's Inlet (102), Batesfordian limestones at Flinders (23, 137) and Keilor (77, 108), and Balcombian marls at Balcombe Bay (36, p. 30; 111) and Curlewis (76, 105), and ironstones at Royal Park (13, 70, 108, 158). While these basalts are probably Oligocene or even older, the older basalt of Maude (106), resting on Janjukian limestones and unconformably overlain by Balcombian limestones, must be of Lower Miocene age. In South Gippsland the Older Volcanic series underlies the principal lignite seams of the Yallourn series, as at Warragul (36), Yarragon (624, 648), Yallourn (624), and Boolara (648), but occasionally is underlain by thin lignite seams, as at Yarragon (648), rarely thicker, as at Elizabeth Creek, Allambee East (648), and Narracan (652*a*), or by lignitiferous sands as at Balcombe Bay (36).

Perhaps referable to a similar Oligocene horizon are the basalts overlying the older deep leads at Emmaville (18) and elsewhere in the New England district of New South Wales, and the basalts of the Redbank Plains series and interbedded in the Silkstone series (633) of South-eastern Queensland, as well as the basalt of Marrawah, on the west coast of Tasmania, pebbles of which occur in the adjacent Barwonian bryozoan limestone (10, pp. 25, 26, 50).

The relationship of these older volcanic rocks to beds containing the *Cinnamomum* flora is a varied one. In Victoria at Bacchus Marsh (9, 28) the basalt is the older, but at Narracan (644), Dargo (643), and elsewhere the leaf beds are covered by basalt, a relation also obtaining at Vegetable Creek (Emmaville) (18) in New South Wales and at Redbank Plains (633) in Queensland.

Alkaline lavas and intrusive rocks, perhaps chiefly of late Tertiary age, are developed in all States except South Australia. By some authors they have been regarded as constituting a middle series of eruptions intermediate in age between the older and the newer volcanic series, both dominantly basaltic; others have associated the alkaline rocks with one or the other of these

main series. Though it is tempting to correlate the alkaline rocks and, indeed, David (2) referred most of them to the Pliocene, in many cases the evidence of age is but slight.

In Western Australia the leucite-lamproites of the Fitzroy River in the West Kimberley district (677, 684) include plugs and fissure intrusions which are post-Permian and may be of Tertiary age.

In S.E. Tasmania the alkaline intrusive rocks of Port Cygnet and Woodbridge (673) are post-Triassic and probably Tertiary. They include alkali-syenite-porphyry, foyaite-porphyry, solvsbergite-porphyry, and tinguaite-porphyry, as well as many other types.

In Victoria alkaline rocks are associated both with the Older Volcanic series (Oligocene to Lower Miocene) and with the Newer Volcanic series (late Pliocene to Pleistocene or possibly Holocene), but chiefly with the latter. To the former have been attributed (656) the phonolite and tinguaite which form pipes and dykes near Harrietville (674) in N.E. Victoria; to the latter belong the alkaline volcanic rocks of the Macedon district (659, 679) in Central Victoria, perhaps in part Upper Pliocene, including solvsbergite, anorthoclase-trachyte, anorthoclase-basalt, oligoclase-basalt (macedonite), woodendite, and limburgite. Trachytes and trachyphonolites or phonolites also occur near Trentham in Central Victoria, near Casterton in South-West and Omeo in North-East Victoria.

In New South Wales alkaline rocks, both extrusive and intrusive, are widespread and have been associated (653) with the older basic series, probably Oligocene to Miocene, but by others have been placed later (2, 681). They include the comendites, trachytes, trachyandesites, and tuffs of the Canobolas Mountains (682) near Orange, the trachytes and phonolites of the Warrumbungle (665) and Nandewar Mountains (666), the comendites and anorthoclase-trachytes of the Lansdowne Plateau (653) near Taree, and the tinguaite laccoliths of the Barigan district (653).

Similar alkaline rocks occur in S.E. Queensland (671), notably the trachytes and tuffs of the Main Range, Fassifern district, and Mount Flinders (669), and the plugs and flows of the Glass House Mountains (664), including pantellerites, comendites, trachytes, and dacite. In Central Queensland the volcanic rocks of Springsure (670) include trachyte, trachyte tuff, and phonolite in their middle portion.

The Newer Volcanic series of south-western and central Victoria, though including Pleistocene and perhaps Recent members, was initiated at a period variously regarded as late (17), middle (663), or early (18) Pliocene or even older (650). The earliest flows in the Western District of Victoria appear, however,

always to be post-Kalimnan, though their relation to the Werrikooian is not fully clear. The Drik Drik basalt has been regarded as pre-Werrikooian (18, p. xxii); those of the Portland district, which may be younger, overlie oyster beds (82, p. 230; 84, p. 446) which the writer (159) has correlated, though not on very secure grounds, with those conformably overlying the Werrikooian shell beds of the Glenelg River. In any case the Tertiary members of the Newer Volcanic series can be regarded as not older than Middle Pliocene, at least in South-west Victoria.

Petrographically (659) they are chiefly olivine-labradorite-basalts, but limburgitic and alkaline types occur. Some of the latter have already been mentioned; of the others, in many instances, the age is post-Tertiary.

Probably to be correlated with the Newer Volcanic series of Victoria are the olivine-basalts of Tasmania (660), best represented on the north-west coast, where they overlie marine Janjukian near Table Cape (131). They also overlie the lacustrine deposits of the Launceston Tertiary basin, and may largely be Pliocene.

In New South Wales a newer basic series of lavas and intrusive rocks has been regarded as largely early Pliocene in age (653, 681). Though known as far south as Moruya (21), the lavas are best developed in the northern part of the State, notably in the New England district. They are largely olivine-basalts, but include andesitic basalts with little or no olivine, as well as alkaline types such as nepheline-basalts and leucite-basalts, and also, in the extreme north, acid pitchstones.

In South-east Queensland an upper division of volcanic rocks (669, 671), largely basic, may be Pliocene, at least in part. They are chiefly olivine-basalts, but andesites and andesitic basalts also occur. Beneath the basalts or intercalated with them at the Springbrook Plateau (653, p. 30) are rhyolites and pitchstones which may belong to the same series, though Richards (669) had regarded the acid lavas and agglomerates of the Macpherson Range (653, p. 30; 671, p. 295; 681, p. 44) as contemporaneous with the trachytes elsewhere.

Basaltic rocks occupy large areas in Central and Northern Queensland, but may in part be post-Tertiary (671, p. 298), since volcanic activity appears to have persisted, as in Victoria, up to Recent times.

In contrast to the olivine-basalts of Victoria are the tholeiites (658) of Western Australia, occurring in the extreme south-west in isolated areas from Bunbury to Cape Gosselin (657) and the Donnelly River. Being antecedent to the Coastal Limestone, which is probably Pleistocene, they may provisionally be referred to the Pliocene.

Diastrophism and Palaeogeography.

Following the recession of the Cretaceous seas, which occupied much of the interior of Australia in Upper Albian time (Tambo series of Queensland and South Australia), and persisted till Santonian and even Campanian time (Cardabia series) in Western Australia (156), the greater part of the continent appears to have been undergoing denudation in early Tertiary time, and marine Eocene deposits are confined, so far as is known, to the extreme north-west and perhaps the south-west.

There is, however, no agreement as to the degree of completion reached by the erosion cycle initiated by the uplift in late Cretaceous or epi-Cretaceous time, which in Queensland was associated with the folding of strata of Albian to Cenomanian age (Burrum and Styx coal-measures). David (2) believed that in Eocene times almost the whole of Australia was a nearly perfect peneplane, while Fenner (689, 690) thought that even in the earliest Eocene the land area might have been very low and level, and in any case by the end of the Oligocene must have developed a high degree of peneplanation, a view accepted by Lewis (690) and by Nye and Blake (10) for Tasmania.

On the other hand, Denmead and Bryan (690) considered that in Eastern Queensland, following a late or epi-Cretaceous orogeny, considerable surface relief (691) was present in Eocene and Oligocene times, instead of a well developed peneplane in the late Oligocene. For New South Wales, Sussmilch (18, 690), and for Victoria, Hills (696), agreed that a Cretaceous peneplane had suffered a late or epi-Cretaceous epeirogenic uplift estimated by the former as 450 to 1,500 feet, and by the latter as more than 2,000 feet. They thus picture tablelands at the commencement of Tertiary time, out of which, according to Sussmilch, an erosion cycle carved by the end of the Miocene a younger or Great East Australian Peneplane, a concept earlier put forward by Andrews (685). Hills (690), however, believed that in Victoria mature dissection of the elevated highland region had occurred by Oligocene times, when the Older Volcanic series was first extruded, but that no well developed peneplane was formed, though flat areas were present notably in the plain tracts of the streams.

In Western Australia, Jutson (690, 700), though allowing the possibility of uplift at the close of the Cretaceous followed by an early Eocene dissection, postulated the reduction of the whole State by post-Cretaceous erosion to a vast plain, probably chiefly by peneplanation, but perhaps marginally by marine abrasion. Since marine Miocene deposits rest on these marginal areas, the planation was regarded as completed by Oligocene or perhaps very early Miocene times.

It is evident that physiographers show a measure of agreement in regard to an early Tertiary erosion cycle following on a probably epi-Cretaceous uplift, but that there is disagreement as to whether this cycle achieved completion by the beginning of the Miocene. It may well be that both views are in some degree correct: that in part, notably in the western half of the Continent, peneplanation was further advanced than elsewhere, while in portions at least of Eastern Australia the more elevated regions had not yet been reduced by erosion. If the older volcanic rocks of South-Eastern Australia are correctly referred to the Oligocene, the topography, though mature, was by no means a peneplane.

If we turn to the evidence of marine sedimentation, we find that the Upper Eocene deposits of North-West Australia and the Upper Cretaceous Carbadia series show marked parallelism of attitude and that both have been folded together (156). But since the highest Cretaceous horizon recorded is probably Campanian, and Paleocene to Middle Eocene beds are as yet unknown, it would appear that the relation is one of disconformity, marking a retreat of the late Cretaceous sea before its readvance in the Upper Eocene (Giralian). Since the date of reading of this paper Spath's recognition of a Maestrichtian fauna (*Journ. Roy. Soc. W. Aust.*, vol. 26, 1940, in press) has been reported by Teichert (703), who regards the Tertiary sequence as conformable to the Cretaceous. The extent of this transgression in the North-West Division of Western Australia remains uncertain, since the evidence of an eastward extension of the Eocene sea to Merlinleigh, 115 miles inland from the present coastline, afforded by the discovery of *Aturia* cf. *ziczac* (569), is vitiated by a doubt as to whether the specimen may not have been transported there by human agency.

The next marine horizon recognized in North-Western Australia is not older than Upper Oligocene, so that there may have been a recession and readvance of the sea in this area. This may also be the period of first marine transgression at the head of the Great Australian Bight, in the Murray basin and along the southern coast of Victoria (Anglesean).

The downwarping which allowed of this was apparently the aftermath of movements of sag (perhaps accompanied at their initiation by volcanic activity), which had permitted the accumulation in Oligocene times of a thick Yallourn series of lignites, sands, and clays in a basin or basins extending in Southern Victoria from the Parwan-Altona area, south-west of Melbourne, easterly past Morwell and the Latrobe Valley nearly to Sale. Whether part of the Yallourn series of non-marine deposits was contemporaneous or penecontemporaneous with the earliest stages of marine transgression (Anglesean ?) in the East Gippsland basin is uncertain, but at all events no thick seams of brown coal

are known to overlie marine Barwonian deposits, while the reverse is frequently the case. There is evidence of some oscillation of the Oligocene shoreline, given by deep bores near Lakes Wellington and Victoria (*infra*, p. 81 and fig. 15).

By the beginning of the Miocene, embayments of the Janjukian sea were already well established in South-eastern Australia, notably in the East Gippsland, South Central and South Western areas of Victoria, and in the Murray Gulf which extended from Aldinga in South Australia, across the site of the present Mt. Lofty ranges, into the Mallee district of North-west Victoria (Mount Gnarr bore (57), 754 feet) and into New South Wales (South Ita bore (134), 420 feet), more than 200 miles inland from the present coastline. In North-west Tasmania the littoral "Crassatella" grits, in places conglomeratic, near Table Cape, laid down in the transgressive phase of the Janjukian sea, contain a fauna closely comparable with that of fairly shallow water but not littoral deposits of the type locality near Torquay in Victoria, with which area the sea was doubtless continuous. At Table Cape the overlying Turritella beds (sandy clays) constitute the succeeding shallow water phase of a cycle of sedimentation which is very incomplete. Approximately at the same time a continuance of sagging movements at the head of the Bight resulted in development of what Jutson (700) has termed the Eucla Gulf, nearly to 200 miles north of the present coastline.

Continued sinking, aided by the reduction of relief due to the early Tertiary erosion cycle, resulted in a maximum transgression, in late Lower Miocene and Middle Miocene times (Batesfordian and Balcombian), of seas in which accumulation of limestones was favoured by the reduction of terrigenous material from the diminished and low-lying land areas. In Victoria the chief basins of sedimentation were, as already noted, in East Gippsland from Orbost to Woodside; in South Central and South-Western Victoria, probably continuous beneath the basalt cover of the Western District; and that portion of the Murray Gulf represented by the Wimmera and Mallee districts of North-west Victoria. These three main areas were partially separated by the Palaeozoic or older rocks of Wilson's Promontory and of the Dundas area respectively. Since the deposits of the Murray Gulf are known chiefly from borings, no definite delimitation of its boundaries can be made, but the northern limit is at least as far as lat. 32° 38′ S. (Buckalow bore (134)) and may be set by the ancient rocks of the Barrier Ranges near Broken Hill, while to the east, marine Tertiary deposits are known in New South Wales in long. 142° 55′ E. (Arumpo bore (94)) and borings in Northern Victoria suggest a boundary in approximately the same longitude (697, p. 299). Towards the outlet of the Gulf an upwarp, probably Pleistocene, has caused the Murray River to expose marine Barwonian (in part Balcombian ?) and overlying Kalimnan (?)

strata in cliff sections from near Overland Corner almost to its exit into Lake Alexandrina. Southerly from these sections borings in the Murray Plains (123) suggest that the Murray Gulf continued down to the Mount Gambier district in the south-east of South Australia, and the deposits of this area are probably continuous with those exposed in the cliffs of the lower Glenelg River in South-Western Victoria.

No evidence of Miocene seas is available along the eastern coastline of Australia, since in these regions subsidences in late Tertiary time (2, p. 174) have left the deposits beneath sea-level and inaccessible to observation. In the south-west, however, the occurrence of marine Miocene deposits on the surface of the Western Australian peneplane (?), as far north as Norseman, 120 miles inland, is evidence of a considerable submergence (690, p. 467; 693; 700; 701); while in the north-west submergence in Miocene times, perhaps from slightly earlier than Batesfordian into probably Balcombian times, is indicated by limestones from near North-West Cape southwards to Carnarvon.

Although the Tertiary rocks are commonly either horizontal or very gently tilted, highly dipping and even vertical strata are known where they have become involved in fault movements, as on the coast near Sellick's Hill (698) in South Australia, at Longford (183, p. 210), near Sale, and at Waurn Ponds in Victoria, where Janjukian limestones have been sharply flexed in a very asymmetric syncline with one perpendicular limb. Folding of Janjukian strata has occurred, however, at the type locality near Torquay (183, 686), where a denuded half-dome shows dips of about 10°, and on the Aire coast, where there is gentle folding (110), with dips of 40° off the Jurassic rocks at Castle Cove. The Balcombian clays and limestones of the type locality of Balcombe Bay show dips of up to 20° and slight contortion of strike (111), and those of Grice's Creek much higher dips, which are attributable to landslips or faulting. At Curlewis, however, folding and faulting (23, 76, 105) occur in strata here assigned to the Balcombian, and at Beaumaris (108, p. 190) a monoclinal or asymmetric anticlinal fold, with a maximum dip of about 25°, is developed in strata not older than Upper Miocene (Cheltenhamian). The date of this folding is uncertain, and may be as late as Upper Pliocene.

In Queensland the orogeny in which strata perhaps as young as Cenomanian have been strongly folded, and regarded by some as epi-Cretaceous (690, p. 470), has been claimed to be Tertiary in age (702, p. 306). In any case folding of Tertiary lacustrine deposits, with dips up to 45° at Baffle Creek, appears to be established (702, p. 309).

In the North-west Basin of Western Australia open folding, in which marine beds from Upper Eocene to Miocene are involved,

has been referred to the late Miocene or Pliocene (67, 74, 156). The folds trend from 10° to 25° east of north and the anticlinal members, of which the Cape Range, Rough Range, and Giralia Range anticlines are the chief, form topographic ridges more or less dissected by stream erosion. Though dips are low, being from 2° to 8°, the large size of the structures, in the case of the Cape Range anticline 25 miles in width and 100 miles in length, has caused marine Tertiary rocks to be elevated to 1,200 feet above sea level. Since the underlying Upper Cretaceous beds (Cardabia series) are folded with the Tertiary strata, it is believed that no marked structural deformation occurred during early Tertiary time, followed, according to David (2, p. 19) by post-Miocene folding due to easterly directed thrusts from the Indian Ocean.

In South-East Australia sagging movements continued through Upper Oligocene to Middle Miocene time, permitting accumulation of marine marls and limestones, under shallower bathymetric conditions, perhaps 15 to 30 fathoms, than previously (27) suggested, to considerable thicknesses, over 2,500 feet at Lake Kakydra (41, p. 35) near Sale, in the centre of the East Gippsland basin, and over 2,000 feet at Portland (57, p. 401) in South-west Victoria. In the Sorrento bore (63) in the Port Phillip area the corresponding thickness is about half this latter amount, and probably the same is true of the Murray Gulf.

By Upper Miocene times (Cheltenhamian) this downward movement had already been arrested, and may have been reversed, and by the Lower Pliocene the Kalimnan seas were shallower, perhaps 10 to 15 fathoms in depth, and probably considerably restricted in extent, though it is difficult to draw exact boundaries. The dominant lithological types are fine sands and sandy clays, with an absence of pure limestones. Evidence of a break in sedimentation is afforded by slightly phosphatic nodule beds at the base of the Kalimnan at Grange Burn in the Hamilton district, and elsewhere, and at the base of the Cheltenhamian at Beaumaris.

In the Middle Pliocene the grey sands and shelly fauna of the Adelaidean alike suggest shallow water conditions, perhaps 5 or 6 fathoms in depth, but their geographic distribution is limited to the vicinity of Adelaide on the north and west. The fauna is rather closely related to that of the Kalimnan, and though it may perhaps be present in the Sorrento and Mallee bores, the Adelaidean stage has not been recognizable with certainty outside the type area. The filling up of the Murray gulf by clastic sediments may have been accompanied by a draining back of the shallowing sea as a result of initiation of upwarp movements in the later Pliocene. At all events towards the close of the Pliocene definitely marine conditions had disappeared from the greater part of the Murray basin, and Werrikooian seas, in which shallow

water and even sub-littoral shell beds and sandy limestones were accumulated, were largely restricted to the extreme south-west of Victoria, adjacent areas in South Australia, and perhaps a former estuary near Tintinara (57, p. 400; 68; 123, p. 185; 179) on the lower Murray plains. The final elevatory movements which drained this Werrikooian sea were post-Tertiary and thus outside the scope of this survey.

There is no unanimity as to the interpretation of the terrestrial record of Miocene and Pliocene times. Woolnough (704, 705) believed the lateritic duricrust of Western Australia was formed during a period, which he regarded as approximately Miocene, of extreme peneplanation, but this conception has been criticized by Clarke (690, p. 467). This surface, which is the "Great Peneplain of Western Australia" of Jutson (700), was thought by him (690, p. 469) to have suffered uplift, commencing in the late Miocene or early Pliocene and interrupted by several intervals of stillstand, during the first of which, in the Pliocene, the wide valleys of the Meckering Level were excavated. Subsequent elevatory movements, probably successive, with warping and some faulting, and chiefly also Pliocene, were thought to have given rise to the present Westralian plateau.

Fenner (688, 689) not only postulated for much of Australia an epi-Miocene gradual uplift, passing in the Pliocene into heavy block faulting and differential uplift, but also tentatively suggested a late Pliocene stillstand with peneplanation in South Australia. While a period of Pliocene stillstand has been supposed for part of Western Australia, as above noted, it was not long enough for peneplanation, though broad valleys were cut. Nor has the hypothesis of late Tertiary peneplanation, though apparently adopted by David (2, p. 91), proved acceptable for Tasmania (690, p. 471) although Lewis (692, p. 401) postulated a late Tertiary peneplain, elevated to 1,400 feet in late Pliocene times, or for Victoria (690, p. 474), where, however, post-Miocene erosion has truncated a fold in Cheltenhamian rocks at Beaumaris.

The period of epeirogenic uplift, with accompanying warping and block-faulting, which initiated the present erosion cycle, was placed at the end of the Pliocene and termed the Kosciusko Period by Andrews (685), who regarded the movement as dislocating a surface with broad shallow valleys. These wide, mature "Upland Valleys" of New South Wales were believed by Sussmilch (18; 690, p. 465) to have been cut during a cycle initiated by an epi-Miocene uplift of the order of 400 feet. There is no general agreement as to whether the period of maximum uplift (Kosciusko epoch) should be regarded as early Pleistocene (685; 689, p. 471) or as late Pliocene (2, 18), which latter is probable in Victoria (695).

Conclusion.

Correlation within Australia.

The writer's views on correlation within Australia are summarized in the accompanying table. Since he believes that only the broadest correlations are possible with Tertiary deposits in distant parts of the world, and that while even internal correlations are not yet satisfactorily established, it is impracticable to equate local stages with those of Europe, the reference in the correlation table to subdivisions of the major European units is a tentative one. For this reason the use of a local nomenclature for stages is important, as has been proved in the parallel case of New Zealand, and its partial discontinuance by some Australian authors is to be deplored as a retrogressive step, tending towards that confusion which the local names were designed to reduce.

Should it be proved, as is probable, that stages exist which are not covered by the names already proposed, further stage names should be introduced, provided they are rigorously defined.

Correlation with the East Indies.

The studies of the larger foraminifera which have already been made enable a provisional correlation with the stratigraphic divisions established by the Dutch geologists in the Netherlands East Indies. Most of this work in Australia has been done by Chapman and by Miss Crespin, whose correlations differ in part from those made elsewhere in this paper and here summarized:—

Europe.	East Indies.	Australia.
	g	
Miocene	*f*	Balcombian marls with *Trillina howchini*. Muddy Creek (Clifton Bank) and Mitchell River (Skinner's), Victoria. Limestone with *Trillina howchini*, *Flosculinella bontanensis*, *Lepidocyclina*, &c. Cape and Rough Ranges, Western Australia. Batesfordian limestones with *Lepidocyclina* cf. *tournoueri* and *L. verbeeki*. Batesford, Keilor, Hamilton bore (Muddy Creek), &c., Victoria.
	e	Limestone with *Lepidocyclina murrayana*, *L. verbeeki*, &c. North West Cape Range, Western Australia.
Oligocene	*d*	Limestone with *Lepidocyclina dilatata*, *L. papuanensis*, &c. North West Cape Range, Western Australia.
	c	
Eocene	*b*	Giralian limestone with *Discocyclina* and *Pellatispira*. Giralia Range, Western Australia.
	a	

TENTATIVE CORRELATION TABLE OF THE TERTIARY ROCKS OF THE COMMONWEALTH OF AUSTRALIA.

		MARINE STAGES.	WESTERN AUSTRALIA.		SOUTH AUSTRALIA.		VICTORIA.		TASMANIA.		NEW SOUTH WALES.		QUEENSLAND.	
			MARINE.	NON-MARINE.	MARINE.	NON-MARINE.	MARINE.	NON-MARINE.	MARINE.	NON-MARINE.	MARINE.	NON-MARINE.	MARINE.	NON-MARINE.
PLIOCENE	UPPER	WERRIKOOIAN		? Laterites developed superficially. Cliefs of Mount Elder Range with *Planorbis barbani*. ? Thuleitic basalt of Bunbury.	? Tintinara bore.	? Arltunga series of Central Australia, sands, clays, and gravels, often with "duricrust," and freshwater limestones in Arltunga district, Eastern MacDonnell Ranges. Silicified "duricrust" of the Interior of Australia, in part.	Ostrea limestone of S.W. Victoria, in part. Shell beds of Glenelg River, Moorabool Viaduct, Sorrento and Mallee bores.	Torrent gravels of East Gippsland. ? Earliest flows of Newer Volcanic series (basalts, &c.). ? Alkaline volcanic rocks of Macedon, in part.	? Wingaroo bore, Flinders Island.	? Basalts of North West Coast.		? Plateau soils, in part. Newer volcanic series (basalts), in part. Sands, gravels, and "grey billy" of Hunter River Valley, South Coast, &c.		? "Red loam" and "red earth" residuals. ? Rhyolites and basalts of South East Queensland. ? Petrie series of sandstones, quartzite, &c.
	MIDDLE	ADELAIDEAN		?? Alkaline volcanic plugs of Kimberley Division.	Shelly sands of Dry Creek, Abattoirs, and other bores near Adelaide.			Younger "deep leads" with fossil fruits at Haddon, &c.		Sub-basaltic leads with fossil fruits, Brandy Creek, &c. ? Lacustrine beds of Launceston and Derwent Basins.	? Ferruginous grits of Moruya.	Sub-basaltic leads of Gulgong with fossil fruits.		
	LOWER	KALIMNAN			? Upper beds of Murray River cliffs and at Aldinga.		Sands and marls of East Gippsland, Muddy Creek (upper beds), upper part of Sorrento, Mallee and Wimmera bores.							
MIOCENE	UPPER	CHELTENHAMIAN	? Limestone of W. side of North-West Cape Range.		? Shell beds in well-sinking at Murdarie.		Sandy marls of upper beds at Beaumaris. ? Middle part of Sorrento bore. ?? Shell marls of coastal cliffs near Sherbrook River.	Leaf beds overlying marine Barwonian at Scotland Rock and (?) Pitfield Plains. Sands, clays, and ironstones with *Cinnamomum* at Bacchus March.		?? Alkaline intrusive rocks of Port Cygnet and Woodbridge.	? Shell beds in well-sinkings at Tarcoola.	? Alkaline lavas and plugs of Canobolas, Warrumbungle, and Nandewar Mountains. ? Plant beds of Warrumbungle Mountains with *Cinnamomum* in trachytic tuffs. Plant beds of Darling Plains, E. of Broken Hill. Quartzite with *Cinnamomum* at Dalton, near Gunning.	? Alkaline plugs of Glass House Mountains and lavas and tuffs of Main Range, Fassifern, Springsure, &c.
	MIDDLE	BALCOMBIAN	Limestone with *Flosculinella* and *Trillina howchini* of Cape and Rough Ranges and Carnarvon bore.	? Lacustrine clays, sands, and conglomerate of Collie River Valley.	Middle beds of Murray River cliffs near Morgan. ? Bryozoan limestone of Mount Gambier.	? Eyre series, sandstones with plant remains, of Lakes Eyre and Torrens.	Shell marls of Mornington, Muddy Creek (lower beds), Fyansford, Barwon Basin, Gellibrand, Mitchell River, and lower part of Sorrento bore. Limestone of upper beds at Maude. Ironstones of Keilor and Royal Park (lower beds).	Lepidocyclina and bryozoan limestones of Batesford, Keilor, Flinders, Muddy Creek bore, and East Gippsland bores.	? Bryozoan limestone near Cape Grim and on Flinders and King Islands.			? Eyre series of West Darling District.	? Eyre series of Central basin.
	LOWER	BATESFORDIAN	Limestone with *Lepidocyclina marrayana* and *L. verbeeki* of North-West Cape Range.					"Older Basalt" of Maude.						? Lacustrine beds of Baffle Creek, Duaringa, &c., and lignite of Waterpark Creek.
		JANJUKIAN	Plantagenet beds (siltstones) of Albany and Cape Riche. ? Limestone of Lake Cowan district near Norseman. Eucla limestone of Great Australian Bight.		? Limestones beneath Nullarbor Plains. ? Lower beds of Aldinga and in Adelaide bores.		Shell marls and bryozoan limestones of Torquay. Limestone of Waurn Ponds and Maude (lower beds). ? Marls and limestones of Aire coast and clays of Cape Otway.	? Deep leads with fossil fruits at Hoddle's Creek and Tanjil. ?? Upper part of Yallourn series.	"*Crassatella*" and *Turritella* beds of Table Cape.	? Leaf beds of Macquarie Harbour.	Shell marl of South Ra bore. ? Ironstone of Arumpo bore.			
OLIGOCENE	UPPER	ANGLESEAN	Limestone with *Lepidocyclina dilatata* and *L. papuaensis* of North-West Cape Range. ? Lower part of limestone in bores on Eucla Plateau.		? Lower beds of deep bores near Mount Gambier.	Sands and pipeclay with leaves, Muslin's Bay, Aldinga. Lignites and leaf beds of Moorlands.	Carbonaceous sands with *Cyclammina* of Anglesea Cliffs, Torquay bore (110–310 feet), and near base of bores in East Gippsland, Mallee (Piega bore), and Dartmoor.	? Yallourn series, lignites, sands, and clays of Morwell and Yallourn. Sands, sandy and lignitous clays beneath marine marls in Balcombe Bay bore; sands, clays, and lignite beneath Balcombian at Altona to Parwan (bores). Lignite and clays of Gnoo Nure bore, East Gippsland; sands and clays at base of Point Addis, Dartmoor, and Mallee bores. Older Volcanic series (basalts, &c.) of Western Port, South Gippsland, &c. Leaf-beds of Berwick, Narracan, Pascoe Vale, &c. ? Deep leads of Stawell and upper Moorabool River.		Basalt of Marrawah.		? Older Volcanic series (basalts) of New England. Vegetable Creek (Emmaville) leads with *Cinnamomum*.	Silkstone series of S.E. Queensland, shales, sandstones, and *Planorbis* limestone with associated basalt. Redbank Plains series of S.E. Queensland with fish and plant remains near Oxley and Purra. Basalts of Redbank Plains and Cooper's Plains.
EOCENE	UPPER	GIRALIAN	*Discocyclina* limestone of Giralia Range and Cape Cuvier, N.W. Division. ? Foraminiferal shales of Perth District, between 120–770 feet in King's Park bore No. 1.	? Freshwater sands and clays between 780–1,950 feet in King's Park bore No. 2.										

BARWONIAN SYSTEM

[Pages 65-64.]

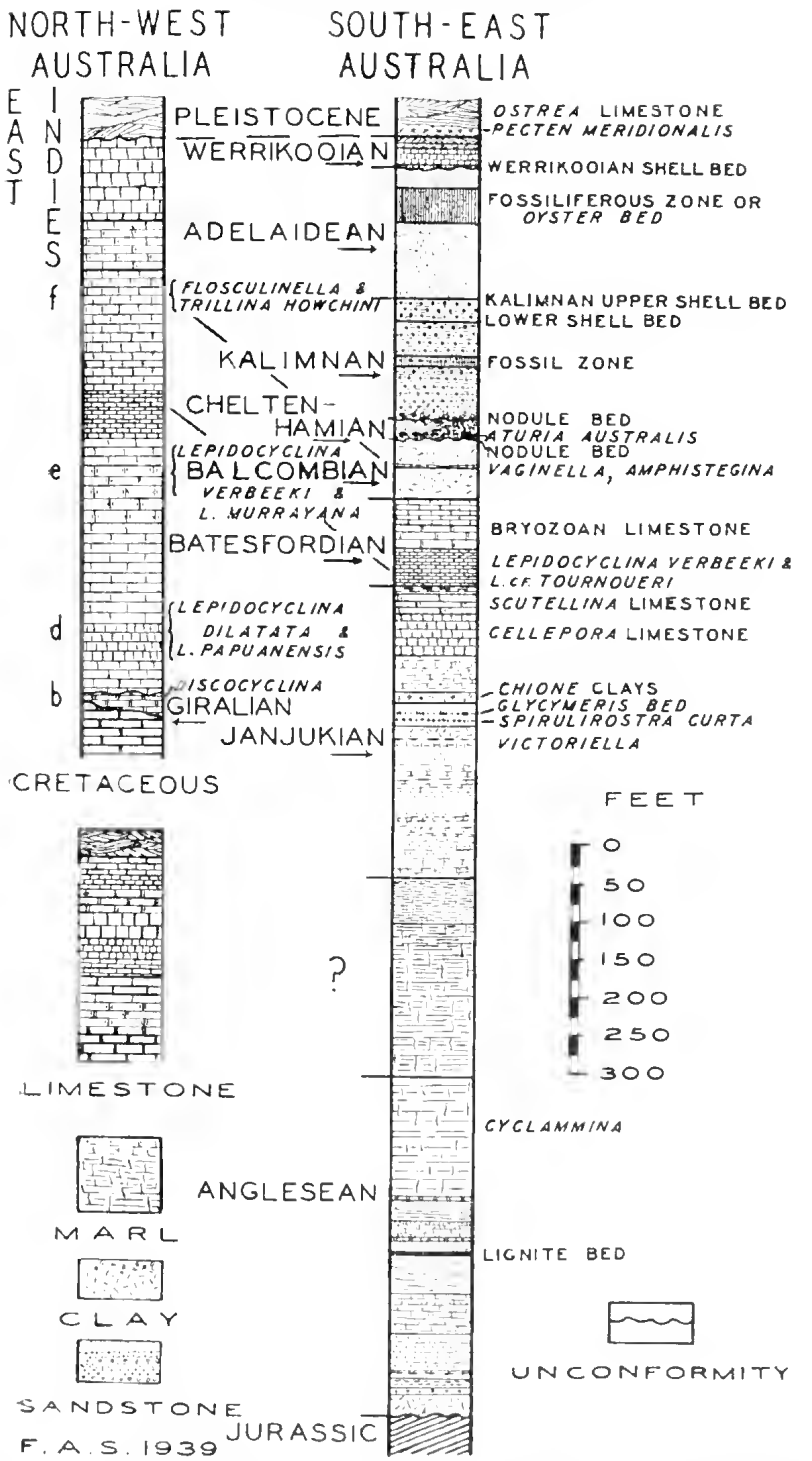


FIG. 11. Composite sections of the marine Tertiary rocks of North-West and of South-East Australia. Broken lines link equivalent horizons in the two sections.

Correlation with New Zealand.

Despite their geographic propinquity, the Tertiary faunas of Australia and New Zealand are notably distinct, at least specifically, and correlation between the two countries is difficult.

At an early date Tate (447) recorded half a dozen species of brachiopods as common to the two countries, but later workers on the New Zealand faunas have accepted (450) only two Australian species. One of these, *Murravia catinuliformis* (Tate), occurs in the *Liothyrella landonensis* fauna, characterizing Allan's Duntroonian stage, regarded by Finlay as the lower member of the Upper Oligocene. The River Murray cliffs (Middle Murravian) constitute the type locality of this species (175), but it has been recorded (275, 543) from localities here referred to Janjukian, Balcombian, and Cheltenhamian stages, a wide range which induced Thomson (450, p. 185) to suggest, probably rightly, that more than one species was included. Until this doubt is resolved the species cannot be utilized for correlation. The other species, *Stethothyris sufflata* (Tate), with Port Vincent on Yorke Peninsula as type locality (543, p. 253), is restricted in Australia to localities (275, 543) belonging to the horizon of Tate's Lower Aldinga series, here referred to the Janjukian. In New Zealand, according to Thomson, it occurs only in the Weka Pass district, ranging from the calcareous mudstone following the main Mount Brown limestone (Hutchinsonian) up to the uppermost Mount Brown limestone (E). It may be noted that Marwick has placed the Hutchinsonian stage as Upper Oligocene, and more recently Finlay (321) as Lower Miocene, while the writer regards the Australian localities as Oligo-Miocene.

The molluscan species supposed identical in the two countries have been listed by Finlay (485), but those critically examined by Marwick (501) proved in all but one case to be represented by allied rather than by conspecific forms, and the same applies to many other records, such as that of the Neozelanic "*Drillia*" *wanganuiensis* Hutton in the type Kalimnan fauna. The exception is *Typhis maccoyi* T. Woods, with which Tate (538) regarded the Neozelanic *Typhis hebetatus* Hutton as synonymous, a conclusion concurred in by Marwick (501). The type locality of the former is Table Cape, Tasmania, to be correlated with the type Janjukian locality of Spring Creek, near Torquay, Victoria, where it is common in the lower sandy marls at the level of Bird Rock, but the species ranges into the Balcombian stage at Muddy Creek, Gellibrand River, and other Victorian localities, though it has not been recorded from Balcombe Bay

itself, as remarked by Pritchard (111, p. 48, footnote). In New Zealand it occurs in the Mount Harris beds which are referable to the Awamoan stage recently regarded by Finlay (321) as Middle Miocene, but previously by Marwick as Lower Miocene. Thus it is comparable in age to the range in Australia, in the writer's view from Lower Miocene or Oligo-Miocene to Middle Miocene.

While generic identities in the Mollusca are seldom of much value except for the broadest correlation, a notable exception is that of the Kalimnan *Heligmope dennanti* Tate (540, p. 329) and the Waitotaran *Turbo postulatus* Bartrum, believed to be congeneric by Finlay (488), since his suggestion that *Heligmope* is ianthinid and thus a pelagic genus is supported by examination of the protoconch of the Australian species. In a second case, that of *Notovola*, this subgenus of *Pecten* had already reached New Zealand by Castlecliffian times, but not Australia until after the end of the Werrikooian, if the definition of this latter stage herein proposed be adopted.

The evidence of other groups is indecisive save perhaps for the Foraminifera. Here the foraminiferal faunule described by Chapman from near Mount Oxford, South Island of New Zealand, contains *Discocyclina* and *Asterocyclina*, an assemblage recalling that from the Giralian stage in North West Australia, but having in addition *Assilina*, relegating it to stage *a* of the East Indian sequence, regarded as Middle Eocene. Finlay (321) has referred the New Zealand occurrence to the Bortonian stage.

The same author (321, 322) has suggested a correlation of the Australian Janjukian with the Waitemata beds (Hutchinsonian) based on his identification from Torquay, the type Janjukian locality, of *Calcarina mackayi* (Karrer), a species restricted in New Zealand to the Waitemata beds (Hutchinsonian). Finlay also records it from Whakan stream, Poverty Bay, with abundant *Nephrolepidina* and *Miogypsina*. This orbitoid-bearing horizon is rather to be correlated with the Australian Batesfordian as herein defined, than with the Janjukian as supposed by Finlay, doubtless owing to Chapman's reference, from which the writer dissents, of the Batesford limestones to the Janjukian.

Attention may also be drawn to *Miogypsinoides dehaarti nitidula* Chapman, which has been recorded by that author (65) from Quobba Cliffs, North West Australia (fig. 1) and also from limestones in the Mount Somers district, New Zealand, which are referred to the Hutchinsonian (Speight, 1938, *N.Z. Geol. Mem.* 3).

A tentative, and probably premature, correlation of the Australian Tertiary stages with those of New Zealand, as set out by Finlay (321), is as follows:—

		New Zealand. (Finlay, 1939.)		Australia. (Singleton, 1939.)	
Pliocene	U.	Castlecliffian		Werrikooian (? new stage)	
	M.	Nukumaruian		Adelaidean	
	L.	Waitotaran Opo'tian		Kalimnan	
Miocene	U.	Taranakian		Cheltenhamian	
	M.	Awamoan		Balcombian Batesfordian	Barwonian
	L.	Hutchinsonian		Janjukian	
Oligocene	U.	Waitakian Duntroonian		(? new stage) Anglesean	
	M.	Whaingaroan	Ototaran	(? new stages)	
	L.	Kaiatan			
Eocene	U.	Takaian	Waimatean	Giralian	
	M.	Bortonian			
	L.				

[Addendum: Allan (443) in a paper bearing the date 9th April, 1940, has described as a new species *Stethothyris epsilon*, the New Zealand brachiopod hitherto identified as the Australian *S. suffiata* (Tate), which latter is transferred to a new genus *Victorithyris*, the two species being homoeomorphs. He has also identified from the Upper Janjukian limestone of "Rocky Point, mouth of Spring Creek, Torquay, Victoria" (443, p. 285) the Neozelanic *Neobouchardia minima* (Thomson), originally described from the main Mount Brown limestone (Hutchinsonian), but ranging downward to the Duntroonian. It may be noted that Allan's "Rocky Point" is local usage for the point immediately south of the mouth of Spring Creek, shown on the military map and in fig. 7 as Jan Juc and to be identified with Pritchard's "Scutellina Limestones" (155). In 1936 Allan did not visit the true Rocky Point (locally also known as Pride's Leap) of fig. 7, the military map and the usage of Tate and Dennant (183, p. 209) and of Hall and Pritchard (107, p. 156). F.A.S., 29.4.40.]

Discussion of Sequence.

In Section III., the writer has attempted to summarize the views of other writers and in Section IV. his own views on the vexed problems of the sequence and correlation of the Australian

marine Tertiary deposits. There remains the necessity to indicate the evidence on which these latter views are based and wherein they may be opposed to those of other workers: such evidence can be here presented only in outline.

The Relation between Anglesean and Janjukian.

In 1910, Hall (102) noted that the black sandstone or sandy clays of the cliffs north-east of the Anglesea River seemed to show a gentle anticline, but attributed it to the effect of weathering following the contour of the ground. He concluded that these black sandy beds were apparently the equivalents of the rich marine beds of Spring Creek, or in other words that the Anglesean and Janjukian were different marine facies of approximately the same age.

Nevertheless, the writer believes the anticlinal structure (see Pl. 1. fig. 1) to be real, and evidenced on the westerly limb by the dip of the junction between the black sandstone and overlying white sands (*supra*, p. 25), although the fold axis may not trend in the direction shown by Coulson (686, fig. 1). To the east between the Black Rocks and Point Addis there is a gap in the coastal section, occupied by sand dunes which thus mask the relation between the Anglesean black sandy beds and the probably Janjukian limestones of Point Addis, though it must be admitted that the latter dip towards instead of away from the Demon's Bluff section. Since, however, gentle folding of the Tertiary strata between Torquay and Anglesea is present, this dip, which is also shown by the erosion surface (44) within the limestones on the west side of Point Addis, probably lacks stratigraphical significance. Of more importance is the evidence of the borings for oil made by the Point Addis Company at Point Addis (37, p. 21), but, although the bore logs are available (38, pp. 17, 18), this is not the case with the cores themselves, which remain undescribed, so that their interpretation remains doubtful. The same applies in a measure to the bores (37; 38, pp. 15-17) put down by the Torquay Oil Wells Company near the Janjukian type locality south-west of Torquay (Fig. 8), though the general sequence has been stated by Chapman and Singleton (27, p. 996, and *supra*, p. 39) and the bore logs (38) have been utilized in the preparation of the composite section in fig. 11, which suggests a possible intervening stage. In the deeper portions of these bores in the Parish of Jan Juc the richly fossiliferous Janjukian beds are underlain by strata probably referable to the Anglesean, which in some cases contain *Cyclammina* and are often lignitiferous towards the base.

This sequence of these stages is supported by the evidence of borings in the Mallee, Dartmoor and East Gippsland districts in the north-west, south-west, and south-east of Victoria respectively.

The Relation between Janjukian and Balcombian.

This, the most controversial topic in Australian Tertiary stratigraphy, requires separate treatment, even though the writer believes it desirable to recognize the Batesfordian as an intermediate stage. It will be apparent from Section III. that Tate and Dennant, though reversing Hall and Pritchard's sequence, here adopted, of the above stages, nevertheless placed the Lower Aldinga beds, here correlated with the Janjukian, at the base of their sequence and hence in an infra-Balcombian position. Although Chapman, the other principal protagonist of the post-Balcombian age of the Janjukian, appears recently to have greatly modified this view (*supra*, p. 11), it is necessary to examine the arguments he has advanced in support of it (23).

Hall and Pritchard relied largely, as does the writer, on the sequence displayed in the valley of the Moorabool River between Maude and Fyansford (map 2; figs. 5 and 12). Their view is based chiefly on the correlation of the lower Maude limestones with the Janjukian and of the Upper Maude limestones, separated from them by the intervening Older Basalt, with the Balcombian, though the local nomenclature had not been instituted at the time of their paper (106). While the lower Maude mollusca include several species apparently restricted to the locality, many of the most characteristic, such as *Eotrigonia intersitans* (Tate) and *Eucrassatella maudensis* (Pritchard), also occur at Torquay, and the correlation with the Janjukian, though unacceptable to Tate and Dennant (185, p. 138) appears justified. The reference of the upper Maude beds to the Balcombian is less well established, though the writer believes them to represent a littoral facies of the Fyansford clays, whose Balcombian age is discussed below. Although detailed mapping of the lower Moorabool valley is desirable, Hall and Pritchard (104, 106, 109) have already shown that the generally downstream dip of the Tertiary rocks results in the disappearance below river level first of the lower Maude beds, followed by that of the Older Basalt, about half way between Bannockburn and the Sutherland's Creek Junction. Downstream from this locality the southerly equivalent of the upper Maude beds is represented by the Batesford bryozoan and lepidocycline limestones (Batesfordian) and the Fyansford clays (Balcombian), which overlie them in turn above Griffin's (fig. 5).

Since the reference of the lower Maude beds to the Janjukian and the general stratigraphical sequence have not been challenged by Chapman, it is evident that the crucial point lies in the age of the clays at Orphanage Hill, Fyansford, which nearly all workers, including McCoy, correlated with those of Balcombe Bay. In 1911 Chapman (455, p. 421) had himself referred the Orphanage Hill locality to the Balcombian, but three years later (23, p. 39) thought its affinities were rather with the Janjukian,

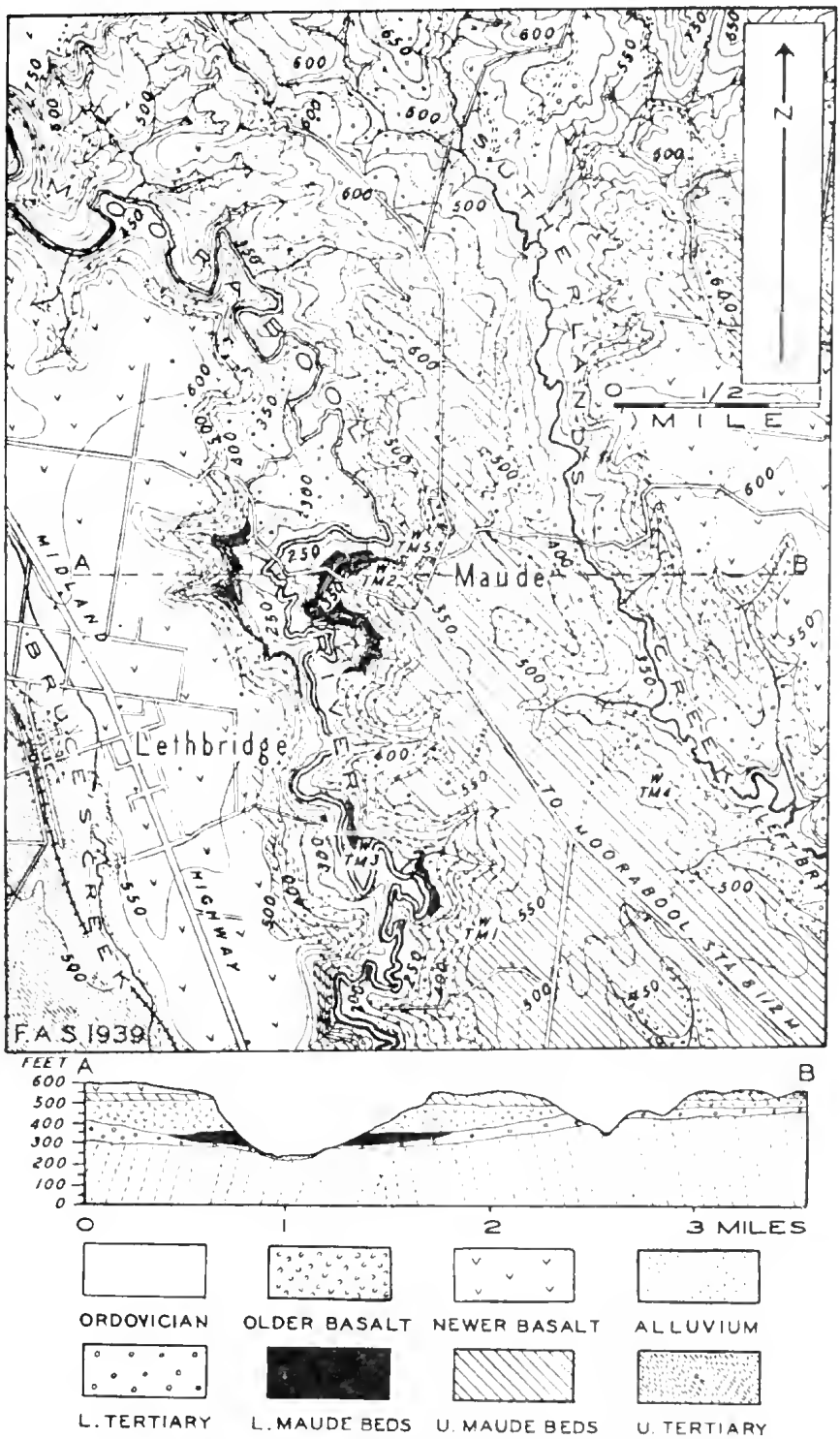


FIG. 12.—Geological map and section of Maude district, Victoria. Geology from Quarter-sheet No. 19 S.W., Geological Survey of Victoria, 1865, with emendations and additions. Contours from Meredith sheet, Military Survey of Australia, 1936.

on the evidence of five of the species recorded by Hall and Pritchard (104), asserted by Chapman to be restricted Janjukian fossils.

The first, *Terebratula vitreoides* T. Woods, although later listed by Crespin and Chapman (450) from Fyansford as a new record, probably refers rather to *T. tatcana* T. Woods (cf. 543, p. 251), which is a *Liothyrella* apparently ranging throughout the Barwonian. The next two, *Natica gibbosa* Hutton and *Pleurotoma haasti* Hutton, are almost certainly wrongly identified with those Neozelanic species. In any case the former has not been recorded from the type Janjukian locality or any other whose correlation with it is undisputed, while the latter was deleted by Hall from his own reference copy of Hall and Pritchard's paper (104) and has been omitted from Dennant and Kitson's catalogue (275). Nor do the last two names cited by Chapman, *Limopsis insolita* (Sowerby) and *Cardita gracilicostata* T. Woods, fare any better. The former was not, in fact, listed by Hall and Pritchard, and has since been shown by the writer (525) to differ from Sowerby's species and has been named *Limopsis chapmani* Singleton, a characteristic Janjukian species. But the Fyansford shells prove to be not "*insolita*" (i.e., *chapmani*) but slightly decorticated examples of *L. morningtonensis* Pritchard, which is a species characteristic not of the Janjukian but of the Balcombian.

An Orphanage Hill shell identified by T. S. Hall as *Cardita gracilicostata* T. Woods, is very much smaller than and almost certainly not conspecific with topotypes from Table Cape of *Venericardia gracilicostata* (T. Woods).

Thus it is seen that none of the five species listed can be claimed as a restricted Janjukian fossil and actually none, save for the erroneously identified *Limopsis* "*insolita*," is recorded from the type locality of the Janjukian by Dennant and Kitson (275). This is significant in that Chapman appears to have regarded as a restricted Janjukian fossil one which is present in beds which he correlates with the Janjukian, such as those in the Barwon-Lower Moorabool basin (referred by Hall and Pritchard to the Balcombian), whether or not it occurs at Spring Creek, Torquay, the type locality of the Janjukian (cf. 57, p. 385, of the Mallee bores fauna: "*Gypsina howchini*, Chapm. A restricted Janjukian fossil, known previously only from Batesford.") This is clearly inadmissable, and species supposed restricted to a stage should either occur at the type locality of that stage or at least only at localities whose correlation with the type locality is undisputed.

On the above criteria a much longer list can be made of restricted or characteristic Balcombian molluscan species in the Fyansford fauna, including *Limopsis morningtonensis* Pritchard, *Eucrassatella dennanti* (Tate), *Cerithium apheles* T. Woods,

Umbilia eximia maccoyi Schilder, *Gigantocypraea gigas* (McCoy), *Austrotriton textilis* (Tate), *Chicoreus lophoessus* (Tate), *Dennantia ino* (T. Woods), *Pterospira hannafordi* (McCoy), *Volutospina antiscalaris* (McCoy), *Conus ligatus* Tate, *Vaginella eligmostoma* Tate.

The Fyansford fauna, then, like that of Murgheboluc, Inverleigh, and other localities in the Barwon River basin, is in actual fact Balcombian and not, as claimed by Chapman, an argillaceous facies of the Janjukian, with a supposed persistence of Balcombian species owing to uniformity of conditions. Argillaceous horizons are well developed in the type Janjukian section, but contain faunas with marked differences from those of Fyansford and Balcombe Bay.

Hamilton District.—In a valuable account of this area Chapman (23) referred the lepidocycline and polyzoal limestone of the Grange Burn, like that of Batesford with which he justifiably correlated it, to the Janjukian, and placed it between the Balcombian of Clifton Bank and the Kalimnan of MacDonald's and Forsyth's. But the Batesfordian limestones at the junction of Muddy Creek and Grange Burn rest directly, as reported by Dennant (83), upon the surface of Palaeozoic quartz porphyry, so that if the Balcombian marls were in an inferior position their absence here could only be attributed to overlap by the limestones. The Hamilton bore (Parish of Yulecart, No. 1) on Muddy Creek, which started on the horizon of Clifton Bank and about 50 chains downstream, penetrated lepidocycline limestones (311, p. 5) which incontestably are the older. The Lepidocyclinae, since the record of *Spiroclypeus* (305) has been shown (311, p. 11) to be erroneous, indicate a Batesford horizon, and true Janjukian strata do not outcrop in the Hamilton area.

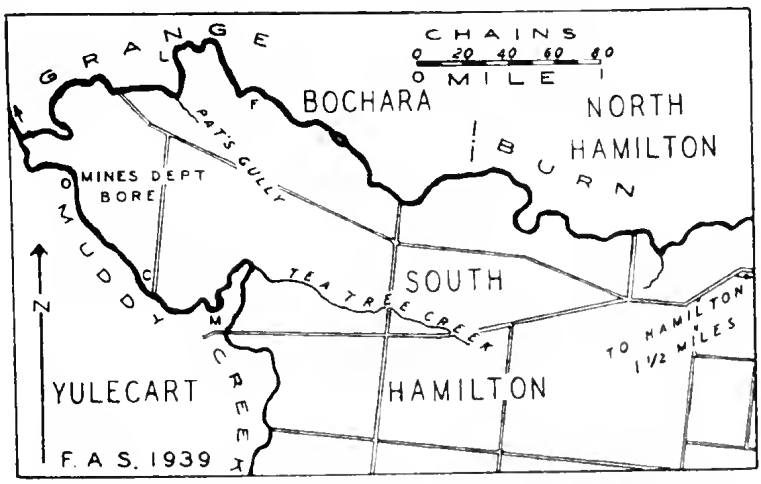


FIG. 13.—Map of Muddy Creek district, near Hamilton, Western Victoria. C, Clifton Bank (Balcombian); F, Forsyth's Bank (Kalimnan); M, MacDonald's Bank (Kalimnan); L, Lepidocycline limestone (Batesfordian).

Sorrento Bore.—While Chapman (63) has correctly referred to the Balcombian the lower horizons of this bore, down to its base at 1,696 feet, his reference of the overlying strata between 758 and 1,295 feet to the Janjukian is based on very inadequate evidence. He ascribed the absence of Lepidocyclinae in the bore to deeper water conditions, but it seems more probable that if the bore were deepened the Batesfordian lepidocycline beds would be penetrated, and possibly also the Janjukian.

Aire Coast (50, 110).—The basal beds at Wilkinson's No. 5 locality or Castle Cove (fig. 14), which dip at about 40° south-easterly off the Jurassic bedrock, consist chiefly of hard ragged limestones whose fauna recalls that of the Lower Aldinga beds in South Australia. Overlying them are grey marly limestones with *Limopsis chapmani* Singleton, a characteristic species of the lower Janjukian at the type locality and also at Aldinga. At Wilkinson's No. 1 locality, Point Flinders, near Cape Otway, black clays contain a rich molluscan fauna (184), referable to the Janjukian, in which the Lower Aldinga facies is prominent.

At Wilkinson's No. 4 locality a Janjukian shelly fauna occurs in grey sandy clays interbedded in a series of clays and bryozoan limestones also dipping south-easterly but at about 20°. At Wilkinson's No. 3 locality, between Nos. 4 and 5, but separated from them by Pleistocene dune limestones, bryozoan limestones, apparently also referable to the Janjukian, dip north-westerly at a little more than 10°.

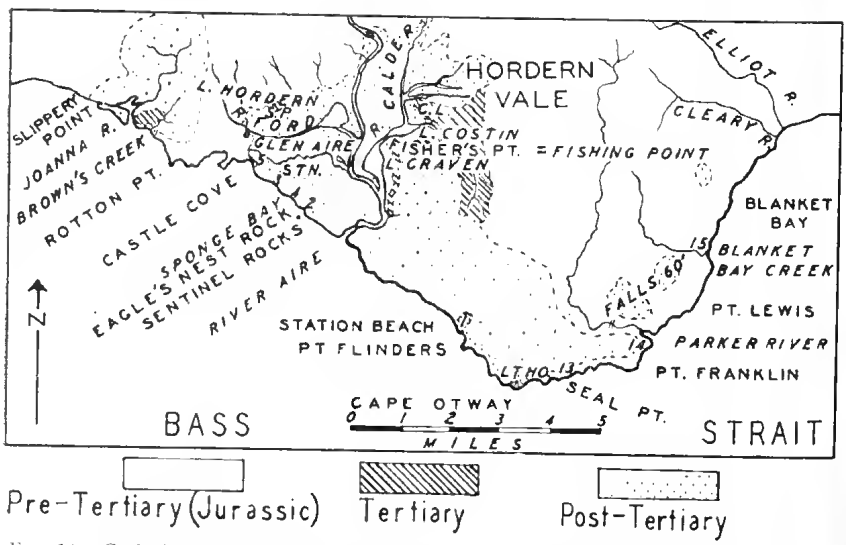


Fig. 14.—Geological map of Aire District, near Cape Otway, Victoria. Modified from maps by Wilkinson, 1865 (50), Krausé, 1874 (34), and Hall and Pritchard, 1899 (110). C.L., Calder limestones. L.T., Lighthouse. S.P., Spud Point. Figures refer to localities numbered by Wilkinson.

About a mile inland from these coastal sections (fig. 14), and separated from them by Pleistocene dune limestones and Recent sand dunes, practically horizontal clays and soft bryozoan limestones outcrop on the left bank of the Calder River from Fisher's Point (or Fischer's Point; Fishing Point of Hall and Pritchard (110) and of Dennant and Kitson (275)) southward. The molluscan fauna (110) of Fisher's Point is clearly Balcombian, though the abundance of *Amphistegina* near the top of the section suggests a horizon similar to that of Clifton Bank, Muddy Creek, where this genus is abundant, and probably slightly older than that of Balcombe Bay, where it is wanting.

Though there is as yet no stratigraphic proof of sequence, it is suggestive, as pointed out by Hall and Pritchard (110, p. 54) that the Janjukian strata of the coastal sections show relatively high dips, due apparently to folding, whereas the Balcombian strata, a short distance inland, remain sensibly horizontal. This may indicate an unconformity between Janjukian and Balcombian beds, for Batesfordian rocks are unknown in this area, though probably the Anglesean stage is represented by the dark clays with *Cyclammina* of Brown's Creek (26, 297).

Mallee Bores.—Though Chapman (23, p. 49; 57, p. 380) has claimed the borings in the Victorian Mallee show a gradual passage from Janjukian to Kalimnan, it is probable the pre-Kalimnan beds are instead largely Balcombian, since the important restricted foraminiferal species *Trillina howchini* Schlumberger, first described from Clifton Bank, is recorded from several of these bores (57, pp. 335, 338, 339, 360) and others in the Mallee (311, p. 6).

The Relation between Janjukian and Batesfordian.

No exposed section is as yet known where this may be demonstrated and reliance must be placed on the relation above discussed between Janjukian and Balcombian, together with the conformable relations dealt with hereunder between Batesfordian and Balcombian.

It is possible, however, that the missing evidence may be supplied by the stratigraphy of the East Gippsland basin (fig. 15), of which numerous bore cores are being investigated. In this area the Batesfordian stage is represented by marly bryozoan limestones with *Lepidocyclina*, which comprise zones B2 and B3 of Chapman and Crespin (25). These authors record them, as Lower Miocene, in the Metung bore (Parish of Bumberrah, No. 1) between 700 and 873 feet, in the Jemmy's Point bore (Parish of Colquhoun, No. 1, or Lakes Entrance, No. 3) between 770 and 840 feet, and in the Rigby Island bore from 685 to 890 feet. This latter, which is Chapman and Crespin's Kalimna bore (26, pp. 118-120) is also known as Lakes Entrance, No. 4, or Kalimna, No. 1. On a lower horizon is their A2 zone, regarded by them as Upper Oligocene and

represented by micaceous foraminiferal marls underlain by glauconitic sandstone. From the micaceous series Chapman and Crespin (25, pp. 6, 7; 26, p. 119) record as restricted foraminifera *Cyclammina incisa* (Stache); *Vaginulina gippslandica* Chapman and Crespin, *Lamarckina glencoensis* Ch. and Cr., and *Victoriella plecte* (Chapman). The last named (267, p. 320; 303) is a restricted species of the lower Janjukian of the type locality, below the summit of Bird Rock, where it is also associated with *Cyclammina*. The micaceous series, occurring in the above mentioned bores at 1,115–1,370, 1,100–1,331, and 1,160–1,385 feet respectively, may therefore be referred tentatively to the Janjukian stage, as may also the underlying glauconitic bed, at 1,396–1,432, 1,331–1,396, and 1,387–1,410 feet respectively, since the writer has provisionally determined therefrom *Turritella* (*Colpospira*) *aldingae* Tate. It may be noted that discrepancies between the above figures and those given by Chapman and Crespin (25, p. 13) are due to supersession of the latter by those of the Boring Records 1923-30 (38, pp. 24 and 89).

The Relation between Batesfordian and Balcombian.

Since these are represented at their respective type localities by strata of contrasted lithology, it might be questioned whether the faunal differences between them may not be due only to differences in facies.

Nevertheless, a conformable succession of Batesfordian by Balcombian strata is demonstrable along the Lower Moorabool River between Batesford and Fyansford (*supra*, pp. 31, 70, and fig. 5) while their superposition was shown beyond doubt by the sections exposed during construction of the tunnel to the new quarry of Australian Cement Ltd. near Batesford.

The Hamilton bore (Parish of Yulecart, No. 1; 38, p. 88) on Muddy Creek (fig. 13), which started near and just below the level of the Balcombian of Clifton Bank, penetrated Batesfordian strata with abundant Lepidocyclinae from 10 feet down to 230 feet (305; 311, p. 5).

At Keilor (77, 108) fossiliferous ironstones, which the writer agrees with Hall and Pritchard in regarding as a littoral facies (108, 155) of the Balcombian, overlie a small exposure of Batesfordian lepidocycline limestone.

At Maude the upper limestones are divisible, as first noted by Tate and Dennant (185, p. 138), into a hard limestone with littoral shells, probably a facies of the Balcombian, and an underlying softer bryozoan limestone. This latter resembles in lithology and fossils part of the Batesford limestones, though *Lepidocyclina* is not yet known to occur.

Since in the first three of the above areas a Batesfordian lepidocycline limestone is succeeded by fossiliferous beds which

are definitely or tentatively referable to the Balcombian, there is strong presumptive evidence for the view that these are distinct but consecutive stages, rather than contemporaneous facies.

Only at Skinner's (91), on the Mitchell River near Bairnsdale, are Lepidocyclinae (311) associated with *Trillina howchini* and with a molluscan fauna of Balcombian affinities. Whether this represents an argillaceous facies of the Batesfordian with its shelly fauna is not yet clear.

The Relation between Balcombian and Cheltenhamian.

This is demonstrated at Beaumaris, the Cheltenhamian type locality (*supra*, p. 32), where the stratigraphic break occurs at the base of a "nodule bed." The underlying Balcombian strata are marls with concretionary limestones which give rise to white pebbles in the shingle. They thus resemble lithologically the beds of Balcombe Bay and Grice's Creek, and are not littoral deposits as stated by Chapman and Crespin (26, p. 122).

At Balcombe Bay (*supra*, p. 27) and at a small gully immediately south of Manyung Rocks, on the coast about a third of a mile south of Grice's Creek, a series of ferruginous sands and grits rests with an even junction upon the fossiliferous Balcombian marls. This ferruginous series is apparently barren at these localities, but at Landslip Point (23, 111) near Frankston, a band containing fossil moulds and casts occurs apparently in the same series. Chapman (23, p. 29; 59) has sought to show that they are referable to the Janjukian, but two of the forms on which he relied are not definitely identified, being listed by him as *Terebratula* (?) *aldingae* Tate and *Pecten* cf. *flindersi* Tate.

Though the type locality of the third, *Pecten praecursor* Chapman, said to be "a specially characteristic Janjukian form" is Spring Creek, Torquay, Chapman cites records from localities such as Shelford, Lower Moorabool and Curlewis-Belmont, whose reference to the Balcombian by Hall and Pritchard (112) is supported by the writer. There is thus little to set against the close resemblance of the rest of the fauna (111) to the Balcombian, and these ferruginous beds, at least in their older part, constitute an immediately post-Balcombian series which may represent wholly or in part the disconformity between Balcombian and Cheltenhamian at Beaumaris.

The Relations of the Cheltenhamian.

The molluscan fauna at the type locality shows an association in a single stratum, about 2 feet above the nodule bed, of Kalimnan species with a subordinate but well-marked Barwonian element. Similarity of preservation precludes a remanié origin for the latter, which, indeed, had induced Tate (181) to correlate these beds with those of Spring Creek, the type locality

of the Janjukian stage. That the Cheltenhamian is post-Balcombian is shown by superposition at Beaumaris (*supra*, p. 32); that it is post-Batesfordian by the discovery by W. J. Parr (personal communication) in the nodule bed and immediately overlying strata of worn and glauconite-filled remanié Lepidocyclinae.

While direct superposition of Kalimnan upon Cheltenhamian strata is not definitely demonstrable, the inferior position of the Cheltenhamian is established on palaeontological grounds. It is even possible that the upper ferruginous sandstone (*c*) of the Beaumaris cliff sections (*supra*, p. 33) may ultimately prove to be Kalimnan and the overlying white sands (*d*), like similar beds throughout the south-eastern suburbs of Melbourne, are probably younger still, perhaps Middle or Upper Pliocene or even, as above suggested, Pleistocene.

The Relations of the Kalimnan.

At the type locality, Jemmy's Point, Kalimna, deep borings show the Kalimnan strata to rest apparently conformably, or at all events without a basal nodule bed, upon a thick calcareo-argillaceous series which in its upper part is presumably of late Barwonian age. Similar relations obtain in many other borings in East Gippsland and also in the Mallee. At Royal Park (108, 158) near Melbourne ferruginous (hematitic) beds, here regarded as Balcombian, are overlain by limonitic beds with a scant fauna which may be Kalimnan. There is no visible unconformity, but a concealed disconformity may be present.

Elsewhere, as at Muddy Creek and Grange Burn, near Hamilton, the typically Kalimnan beds of MacDonald's and Forsyth's are separated from the underlying Balcombian by a thin nodule bed marking a stratigraphic break. The relation of the Kalimnan to succeeding beds is obscure, but it may be noted that many of the beds referred to the Kalimnan in the Melbourne district may equally well be post-Kalimnan.

The Relations of the Adelaidean.

Since beds of this stage are known definitely only from borings, stratigraphical evidence is limited. Nevertheless, the shelly fauna of the Adelaidean shows a marked Kalimnan relationship, so that the two were correlated by Mrs. Ludbrook (140) and some earlier authors (27, 112). The Adelaidean fauna contains, however, at least twice the percentage of living species and it is probably post-Kalimnan (44, 126, 177, 275), a position perhaps supported by the evidence of the Abattoirs bore (fig. 3).

On the other hand, there is sufficient difference between the Adelaidean and Werrikooian faunas to suggest a possible intervening stage yet to be recognized, and Howchin's equation (5) of the two stages cannot be justified.

The Relation between Werrikooian and Pleistocene.

Whether the Werrikooian should be included in the Tertiary or in the Pleistocene has long been the subject of debate. Originally these beds were regarded by Dennant (82, 84) as Pleistocene; then by Tate and Dennant (183) as Newer Pliocene; by Tate (144, p. 84) as Older Pleistocene; by Hall and Pritchard (112) as Pliocene; and by Dennant and Kitson (275), Chapman (22, 23), Chapman and Singleton (27), Chapman and Crespin (26), and the writer (17, 44) as Upper Pliocene. The changes of view by Tate and by Dennant were due to varying opinions as to whether or not most of the extinct molluscan species were of extraneous origin. The writer (43, p. 983) has shown that many of these are in actual fact derived from outcrops of Barwonian clays along the Glenelg River, washed out specimens from both horizons having been indiscriminately collected, and therefore suggested that the Werrikooian might have to be removed to the Pleistocene as advocated by Tate. Nevertheless, a critical study has shown that about 5 per cent. of the mollusca are extinct species, so that the Werrikooian may be placed as Uppermost Pliocene (159), immediately preceding the Pleistocene with a molluscan fauna of living species only.

The stratigraphic succession supports this view (*supra*, p. 47), but if the Pleistocene be marked by *Pecten* (*Notovola*) *meridionalis* Tate, then the Dartmoor oyster bed (*supra*, p. 48) must be referred to the Pleistocene rather than to the Werrikooian as done by Chapman and Crespin (26, p. 124).

The Relations of the Yallourn Series.

Since at the type locality marine Tertiary formations are absent, the difficulty arises that where relations between marine and non-marine strata obtain, the correlation of the latter with the Yallourn series may be unjustified. Indeed, this objection has been raised by Sussmilch (18, p. xv) to the writer's correlation (17) of the Yallourn lignites with the much thinner lignites underlying marine strata further to the east (*supra*, p. 50). It must be conceded that the attenuated non-marine strata beneath the marine Barwonian of the western part of the East Gippsland Tertiary basin are not equivalent to the whole thickness of the Yallourn series. Thus far Sussmilch's criticisms may be accepted, but not his claim that the upper part of the Yallourn lignites, with plant remains, might be as young as Lower Pliocene.

The thickness of the Yallourn series at Morwell was asserted by Sussmilch (18) to be comparable with that of the marine strata of East Gippsland, but the latter reaches 2,588 feet at the Lake Kakydra bore (Parish of Nuntin, No. 2) near Sale (41, pp. 30, 35), which also passed through 455 feet of lignite seams and non-marine sediments interbedded with marine horizons

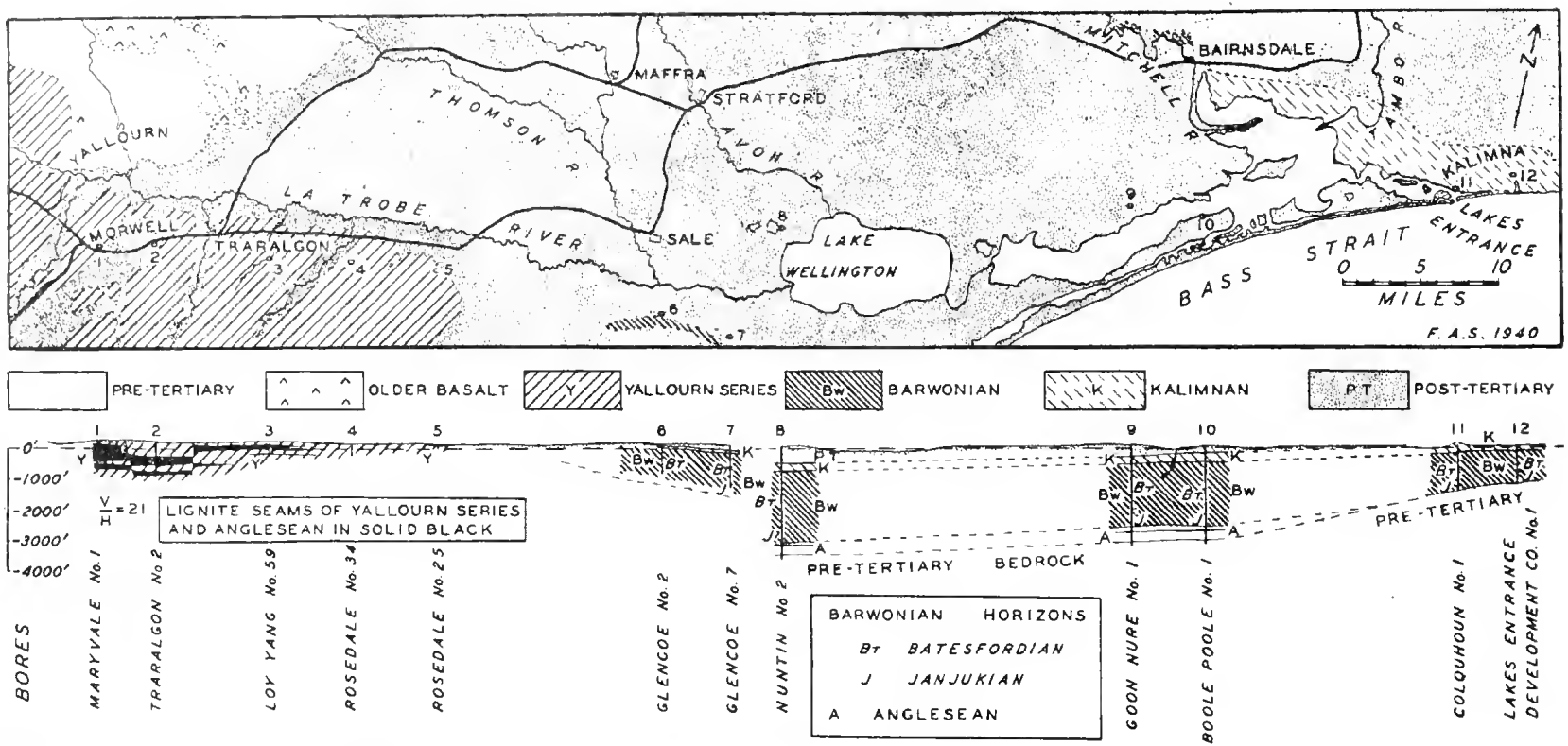


FIG. 15.—Geological map of part of East Gippsland, Victoria, and sections in the Latrobe Valley (bores 1-7) from Morwell to 4 miles E. of Longford and in the Gippsland Lakes area (bores 8-12) from Lake Kakydra to Lake Bunga. Modified from Geological Survey of Victoria maps and boring records (36, 38, 39, 40, 41, 624).

(Anglesean?) before reaching bedrock at 3,480 feet. In any case the rate of accumulation of lignites is probably greater than that of the marine sediments, and even the upper part of the Yallourn series is unlikely to be younger than the lowest part of the Barwonian (*supra*, pp. 50, 57), while the main portion is probably approximately equivalent to the Anglesean.

The general relations in the East Gippsland Tertiary basin are shown by two sections in fig. 15. The bores in the Parish of Glencoe did not reach bedrock, but showed equivalent Tertiary horizons at a much higher level than in the Lake Kakydra bore (Nuntin No. 2) which is probably near the deepest part of the Tertiary basin. This difference of level may well be accounted for by the strong northerly dip shown by Parish of Glencoe borings Nos. 1–5 and by outcrops at Le Grand's Quarry, Longford, in the same Parish.

The lignitic series to the north-west of Port Phillip from Altona to Parwan underlies Balcombian fossiliferous marls and is thus pre-Middle Miocene, but the lower limit of age is uncertain. At Altona an early boring is said to have encountered shells in "fine white quartz-drift" below the brown coal (108, p. 218; 648, p. 82).

Borings (38, pp. 42, 57) south-west of Parwan (Parish of Mouyong, Nos. 2 and 6) have penetrated a 6-ft. lignite seam with fossiliferous marine strata above and below: unfortunately, these faunas have not yet been studied. Beneath in No. 2 bore is a thicker lignite probably correlable with that of Altona.

Small seams of lignite occur, as above noted, beneath the marine beds of the East Gippsland basin south of Sale and of Bairnsdale, in the Tyabb bores (36, p. 28), and a 15-ft. seam beneath the type Janjukian in Torquay bore No. 4 (38, p. 17).

In South Australia the Moorlands lignite (613, 640) also underlies marine Barwonian. The only lignites that come into direct relation with probable Lower Pliocene marine rocks are near Gelliondale in South Gippsland, where they underlie a marine fauna referred by Chapman and Crespin (26, p. 120) to the Kalimnan. Thus they are pre-Kalimnan, but how much older is uncertain.

Though all these occurrences of lignites are not necessarily on the same horizon, in general they agree in being antecedent in the main to the principal or Barwonian marine deposits, and it is therefore not unreasonable to refer the bulk of the lignitic series to the Oligocene.

The Relations of the Older Volcanic Series.

Where the Older Volcanic series or Older Basalts come into relation with Tertiary marine rocks, they are usually unconformably overlain by Janjukian, Batesfordian or Balcombian

deposits (*supra*, p. 53), except at Maude, where the older volcanic rocks occur between the lower and the upper Maude beds.

Airey's Inlet.—At Eagle Rock and Split Point near Airey's Inlet (102, p. 49), the eroded surface of basalt flows and tuffs of the Older Volcanic series is overlain by bryozoan limestones which have been correlated (102) with the limestones of the Upper Janjukian of the type section. It is, however, possible that the horizon may ultimately prove to be lower in the Janjukian stage. It may be noted that none of the deep borings at the type locality (38, pp. 15–17) encountered basalt.

Flinders.—Bryozoan limestone with *Lepidocyclina* and calcisponges rests on the eroded surface of "Older Basalt," which is here of great thickness, though locally there intervenes a thin conglomerate of basaltic pebbles. The section given by Chapman (23, p. 33) is in error in showing the limestone as Janjukian and the overlying material as decomposed Newer Basalt. The former is Batesfordian and the latter, as correctly shown in Kitson's section (137), is clay washed down from weathered Older Basalt at a higher level. Newer Basalt is unknown on Mornington Peninsula.

Keilor.—At Green Gully near Keilor, a small exposure of Batesfordian limestone (77) rests directly on Older Basalt and is itself overlain by ironstones with a shelly fauna probably of Balcombian age (17, 108).

Royal Park.—In the railway cutting south-west of Royal Park station (108, 158), the eroded surface of Older Basalt is overlain by ferruginous sandstones and ironstones with a fauna similar to that of Keilor and like it referred by Hall and Pritchard and the writer to the Balcombian, but by Chapman to the Janjukian.

Mornington District.—At Grice's Creek, Hall and Pritchard (111, pp. 39, 44) described the Balcombian clays as dipping at a high angle towards the basalt and then at a still higher angle off it, and regarded the igneous rock as the older. The writer agrees with this sequence, but believes the dip of the clays, as shown by the intercalated concretionary limestones, to be uniformly away from the basalt in a downstream direction: the junction is obscure and may be due to faulting.

Chapman, however, gave a generalized section (23, p. 30) showing the basalt as intercalated between the Balcombian clays and an overlying ferruginous series referred by him to the Janjukian (59), a correlation above criticized (p. 77).

At Balcombe Bay the Older Basalt is exposed at the first point south of the Cement Works, but its relation to the Balcombian clays north of the Cement Works is obscure, and

little light is thrown on it by Hall and Pritchard's (111) and Chapman's (23, p. 26) sections. The writer believes a fault with northerly downthrow intervenes between this point and the cement works. Decisive evidence as to the position of the basalt beneath the Balcombian at its type locality has since been furnished by Parish of Mooroodue bore No. 6 (36, p. 30, and *supra*, p. 27).

Curlewis.—Here also, as first shown by Hall and Pritchard (105) and recently confirmed by Coulson (76), the Older Volcanic tuffs and basalt are antecedent to the Tertiary clays and bryozoan limestone, and not younger than them as originally supposed by Daintree (79), whose sketch section has been reproduced by Chapman (260, p. 215). The last-named author (23) agreed with Daintree in placing the main volcanic series above the limestone, but regarded the underlying blue clay as itself resting on an ash bed, the clay and limestone being referred to the Janjukian. The fauna of the clays is, however, Balcombian, and the whole of the volcanic rocks pre-Balcombian.

Maude.—The occurrence of a considerable thickness of basalt between marine Tertiary beds in the valley of the Moorabool River near Maude (*supra*, p. 70, and fig. 12) has been admitted by all observers. There is, however, disagreement as to the age of the overlying marine strata, the Upper Maude beds having been referred by Hall and Pritchard (112) to the Balcombian and by Chapman (23) to the Janjukian, and as to whether there is a second flow of basalt intercalated in the lower part of the Upper Maude beds.

On Quarter-sheet No. 19 S.W. of the Geological Survey of Victoria, 1865, mapped by C. S. Wilkinson and R. A. F. Murray, a thin limestone is shown within the upper part of the Older Volcanic series, but Hall and Pritchard (106) were unable to find any evidence of it in the field. Chapman (23, p. 42), however, claimed this could be seen below Maude township on the Knight's Bridge road. After examination of this section and others in the district, the writer unhesitatingly supports Hall and Pritchard's view. At the spot cited by Chapman and immediately north of the outcrop on the Knight's Bridge road of the hard bryozoan limestone of the Upper Maude beds, there are two small excavations. In the upper quarry 2 ft. 0 in. of cross-bedded bryozoan limestone rest on 1 foot of hard bryozoan limestone, and this upon very decomposed basalt. Between this exposure and the road the lower quarry shows basalt, vesicular at the base, at a lower level. In neither case is the lower limit of the basalt visible, and Chapman's belief in an intercalated basalt flow 18 inches in thickness may be due to his having produced laterally two basalt-limestone contacts at different

levels. The alternative view of the writer is that the eroded surface of the basalt, on which the limestone rests, is a very uneven one.

Other traverses on the left bank of the Moorabool River also fail to show any trace of a later flow of Older Basalt, enclosed within the Upper Maude beds. In some of these traverses the marine Tertiary beds are underlain by varying thicknesses, from a few feet upwards, of non-marine sandstones or pebble beds (16, 23, pp. 40, 41). These appear to be absent in the second gully north of the Knight's Bridge road, where the sequence, with approximate thicknesses, is from above—

Upper Maude beds (52 feet).
  Sandy marls with calcareous concretions and a ferruginous grit band about 10 feet from top (30 feet?).
  Hard limestone, bryozoan in lower 2 feet (15 feet?).
  Basaltic pebble bed (1 foot).
Older Basalt (80 feet).
Lower Maude beds (65 feet).
  Sandy rubbly limestone (20 feet?).
  Fine bedded sandy limestone (8 feet?).
  Massive sandy limestone (12 feet).
  Fine sandy marls, with some discontinuous pebble bands (25 feet).
Ordovician slates and sandstones.

Succeeding the Upper Maude beds immediately to the north of Maude township is Newer Basalt of about 50 feet thickness, overlying marls and a hard sandstone, which are possibly to be separated from the Upper Maude beds and to be referred to the Pliocene.

The Older Volcanic rocks of Maude are thus, in the view of Hall and Pritchard and of the writer, post-Janjukian and pre-Balcombian; those of Airey's Inlet are at latest pre-Upper Janjukian. Whether those of Curlewis and Mornington, which are overlain by Balcombian marls, are to be correlated with those of Maude or with those of Airey's Inlet, as is here done, remains uncertain.

Summary.

Marine Tertiary formations form a discontinuous fringe along 5,000 miles of the west and south coasts from North-West Cape in Western Australia to near Lakes Entrance in Victoria, and in N.W. Tasmania. Differing views as to their classification in S.E. Australia have been expressed by McCoy and the Victorian Geological Survey, by Tate and Dennant, by Hall and Pritchard, and by Chapman and his associates.

To the Upper Eocene are referred *Discocylina* limestones in the Giralia Range at the head of Exmouth Gulf, and elsewhere in N.W. Australia; and perhaps also shales with a faunule of smaller foraminifera from deep borings near Perth, in S.W. Australia. Probably Upper Oligocene are *Eulepidina* limestones

in the N.W. Cape Range and the earliest marine strata of S.E. Australia. Chiefly Lower to Middle Miocene is the main development of marine Tertiary strata, including *Nephrolepidina* limestones as well as richly fossiliferous clastic sediments, and several stages may be recognized in Victoria, where Upper Miocene may also be present. Marine Pliocene beds, in at least three stages, occur in S.E. Australia.

The marine stages, which are formally defined and whose stratigraphical relations are discussed, are from older to younger, Giralian, Anglesean, Janjukian, Batesfordian, Balcombian, Cheltenhamian, Kalimnan, Adelaidean, Werrikooian, with probable new stages to be interpolated before and after the Anglesean and between Adelaidean and Werrikooian.

Correlation with adjacent countries is not far advanced, but foraminiferal faunules indicate that stages *b*, *d*, *e*, *f* of the Netherlands East Indies are represented in Australia. Only approximate correlation with stages in New Zealand is as yet possible.

Non-marine deposits occupy wide areas, especially in the interior, but are difficult to date except in the south-east, where they come into relation with marine deposits. Important lignites, chiefly Oligocene, are developed notably in Victoria. Other deposits, mainly fluviatile or lacustrine, may be tentatively referred to various horizons from Eocene to Pliocene, but can seldom be satisfactorily correlated, since the terrestrial vertebrate fauna is almost unrepresented prior to late Pliocene times.

Igneous rocks, largely basaltic, but including alkaline and acid lavas and intrusions, are well developed on horizons from at least early Oligocene to late Pliocene. The basic lavas are chiefly tholeiites in Western Australia and olivine-basalts in Eastern Australia, where more alkaline types include olivine-nephelinites, leucite-basalts, trachyphonolites, tinguaites, trachytes, and solvsbergites, while acid lavas, rhyolites, pitchstones, and dacites, occur mainly in S.E. Queensland. Perhaps Tertiary, are the leucite-lamproites of the Kimberley district, N.W. Australia.

Diastrophism, thought to be late Miocene or Pliocene, has folded Tertiary rocks in N.W. Australia, where, in the Cape Range anticline, marine Tertiary rocks have been upwarped to 1,200 feet above sea level. In S.E. Australia the marine Tertiary deposits, though commonly nearly horizontal, in places show gentle folding with dips of 10°–20°, while locally they may even be vertical where involved in fault movements. Downwarping has permitted marine transgression, reaching a maximum in Miocene times, to distances from the present coastline of 250 miles in the Murray River basin and probably nearly 200 miles in the region north of the Great Australian Bight. In such downwarped

areas lignites totalling 780 feet in thickness occur in the Latrobe Valley in Victoria, while in other areas marine Tertiary deposits reach thicknesses of more than 2,500 feet. Elsewhere block-faulting has raised them to 900 feet above sea level.

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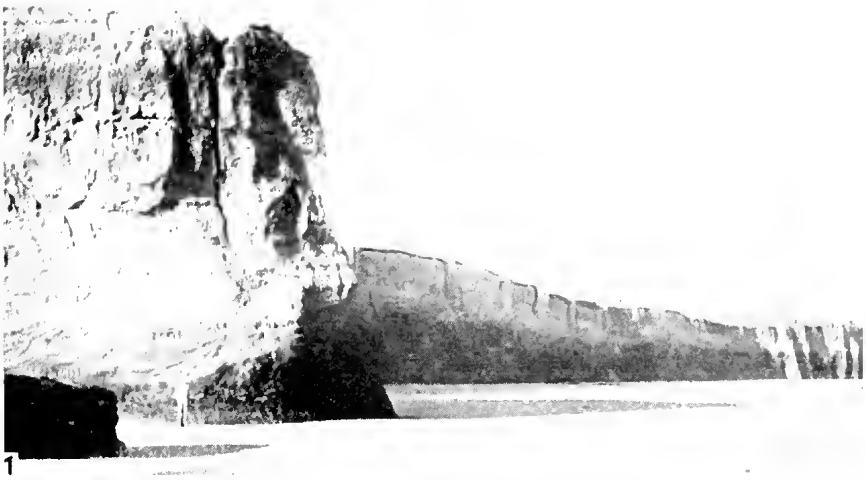

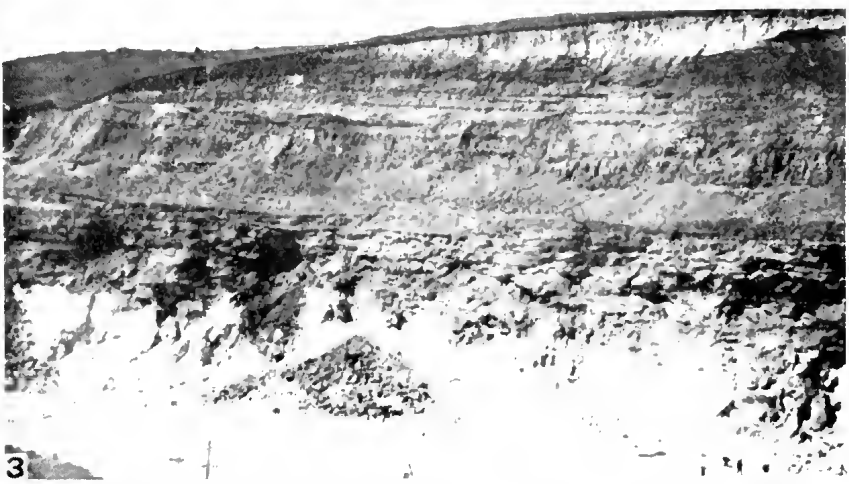

Fig. 1.—Anglesea, V. (Anglesean). Fig. 2. Balcombe Bay, V. (Balcombean). Fig. 3.—Batesford, V. (Batesfordian).

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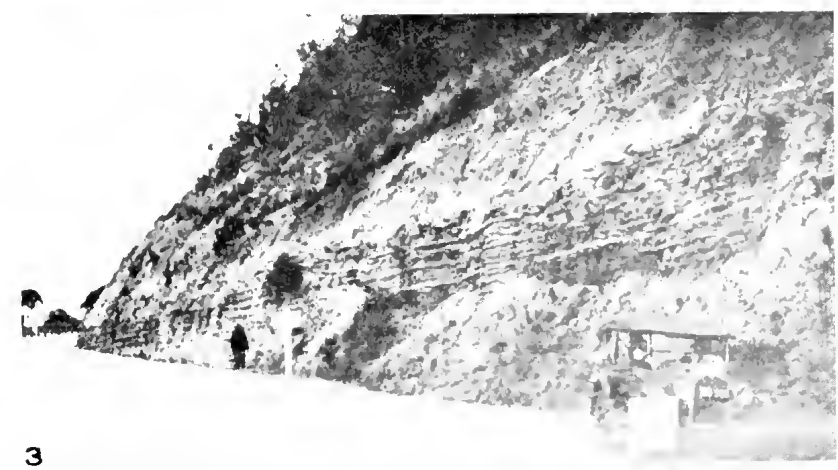

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Fig. 1. Beaumaris, V. (Cheltenhamian). Fig. 2. Torquay, V. (Janjukian).
Fig. 3.—Kalimna, V. (Kalimnan).

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Fig. 1.—River Murray, S.A. (Murrayian). Fig. 2.—Glenelg River, Vic. (Werrikoolian). Fig. 3.—Yallourn, Vic. (Yallourn Series).

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Explanation of Plates.

Plate I.

Fig. 1.—Coastal cliffs between Demon's Bluff and mouth of Anglesea River, half a mile east of Anglesea bridge, Parish of Jan Juc, Victoria: type locality of Anglesean Stage. View N.E., showing dark Anglesean sandstone overlain by white sands, with rock stack in foreground and anticlinal axis hidden in bay behind projecting point. (See p. 25.) F.A.S. Photo.

Fig. 2.—Coastal cliffs 150 yards north of old cement works, Balcombe Bay, a mile and a half south of Mornington, Parish of Moorooduc, Victoria: type locality of Balcombian Stage. View S., showing grey marls (*k*) with concretionary limestone bands in lower portion, overlain by ferruginous sandstone (*g–i*) near top of cliff. Fossiliferous beds (*f*) outcrop chiefly on beach floor between fallen blocks of sandstone. (See p. 27.) F.A.S. Photo.

Fig. 3.—Upper quarry of Australian Cement Ltd, on left bank of Moorabool River, a mile south-south-east of Batesford, Parish of Moorpanyal, Victoria: type locality of Batesfordian Stage. View E.N.E., before diversion of river across quarry floor, showing Batesfordian Lepidocyclina limestone (*a*) passing up into white bryozoan limestone (*b*) overlain by darker earthy limestones (*c*). At level of upper talus band these are overlain by Balcombian clays and marls (*d*), followed at the top by ferruginous sands (*e*) (Kalimnan?) white sands (*f*) (Werrikooian?) and a capping of basalt (*g*) in right upper corner. (See p. 31.) F.A.S. Photo.

Plate II.

Fig. 1.—Coastal cliffs 150 yards east-north-east of site of former baths (marked by piles), Beaumaris, Parish of Moorabbin, Victoria: type locality of Cheltenhamian Stage. View W.S.W., showing hard band of sandstone in right foreground, under which is a shell-bed (marked by figure near rucksack), with nodule bed about 2 feet below beach level. Lower part of cliff is of fossiliferous sandstone (*a*) followed by sandy marl (*b*); upper part of hard ferruginous sandstone (*c*) capped by white sands (*d*). (See p. 33.) Nodule bed outcrops on beach floor from site of baths to far side of boatshed, the anticlinal axis being in line with hotel on cliffs. From boatshed to Table Rock in extreme distance cliffs are of ferruginous sandstone, with Lovenia bed in lower third, capped by white sands at top. F.A.S. Photo.

Fig. 2.—Coastal cliffs opposite Bird Rock (rock stack on left), one and a half miles south-west of mouth of Spring Creek, Torquay, Parish of Jan Juc, Victoria: type locality of Janjukian Stage. View S.S.W., showing sandy marls from base up to capping of Bird Rock, followed by glauconitic clays ("Chione clays") forming ledge at base of cliff on right, in turn overlain by clays and limestones of upper beds. (See p. 39.) F.A.S. Photo.

Fig. 3.—Road-cutting immediately west of bridge over North Arm, half a mile east-north-east of Jemmy's Point, Kalimna, Parish of Colquhoun, Victoria: type locality of Kalimnan Stage. View W., showing, from above, post-Kalimnan sandy clays (*i–j*), white upper shell bed (*h*) resting on hard sandstone (*g*) and sandy marls with harder bands (*f*). Hard band (*e*) reaches road level at foot of figure. Underlying beds are obscured by talus, but outcrop, including lower shell bed (*c*), to right of limit of photograph. (See p. 41.) F.A.S. Photo.

Plate III.

Fig. 1.—Cliffs on right bank of River Murray, half a mile above Morgan, near North-West Bend, South Australia. View N.N.W., showing calcareo-argillaceous sandstones and arenaceous limestones of Middle Murravian, overlain near top of cliffs by Upper Murravian sandstones and capped by oyster beds. (See p. 43.) F. A. Cudmore Photo.

Fig. 2.—Caldwell's Cliff, eastern end, on right bank of Glenelg River, a mile and three-quarters south of Limestone Creek junction, Parish of Werrikoo, Victoria: type locality of Werrikooian Stage. View W.S.W., showing from above, flaggy and concretionary limestone (*i–c*) overlying Werrikooian shell bed (*b*) resting unconformably on Barwonian bryozoan limestone (*a*). See p. 47.) F.A.S. Photo.

Fig. 3.—State Electricity Commission's Open Cut, Yallourn, Parish of Narracan, Victoria. View S.E., showing 200 ft. lignite and 30 ft. clays and sands of Yallourn Series. (See p. 48.) State Electricity Commission Photo.

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Art. II.—*Outbreaks of White Spot or Ichthyophthiriasis* (Ichthyophthirius multifiliis Fouquet, 1876) *at the Hatcheries of the Ballarat Fish Acclimatization Society with notes on Laboratory Experiments.*

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[Read 11th April, 1940; issued separately 1st February, 1941.]

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Occurrence of the Disease.
Life Cycle of the Parasite. Conditions Favouring an Outbreak of the Disease.
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Control Measures.
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Summary.

Introduction.

This work has been carried out in my capacity as Biologist on the Victorian Fresh Water Research Committee. This Committee, which is an honorary one, conducts investigations into fresh water problems throughout the State. White Spot is one of the varied problems which have been studied in the three years of the Committee's existence. My own work was carried out in the Zoology Department, University of Melbourne, and two visits were made to the hatcheries at Ballarat .

The parasite responsible for this disease has been introduced into Australia and one certain source is from imported ornamental carp. It is impossible to state the first date of entry; only in recent years has the disease been of any great economic importance. Previous to that it had been observed in private aquaria over a considerable period, frequently causing the death of small exotic fish.

Outbreaks of this disease, on an epidemic scale, occurred at the hatcheries late in the 1938-39 season when yearling trout were infected, and again early in the 1939-40 season when trout fry were infected. The first outbreak occurred on 3rd April, 1939, and the second was reported on 21st November, after having appeared some days earlier. Both outbreaks showed up very suddenly and were severe in their effect. The losses for the two seasons are set out in Table 1.

TABLE I.—Losses caused by White Spot.

	Brown Trout.	Rainbow Trout.	Total Losses.
1938–39	50,000	30,000	80,000
1939–40	275,000	95,000	370,000

The parasite population probably was building up prior to the recognition of the disease and under suitable conditions reached epidemic proportions.

This report refers in particular to the second outbreak although mention will be made of the first when it differs in some respect from the second.

Occurrence of the Disease.

Serious epidemics have been reported from time to time in France, Holland, Germany, and in various parts of the United States of America. The disease was first recorded in 1869 in the Zoological Garden in Hamburg, Germany, and in France in 1876, where careful observations were made and the name *Ichthyophthirius multifiliis* was proposed by Fouquet for the pathogenic organism—(Prytherch 1924).

In October, 1929, an epidemic at the Ballarat hatcheries was reported to be White Spot but the description of the symptoms in the Minutes of the Society does not warrant such a conclusion. The outbreak was not investigated on that occasion.

An outbreak of White Spot occurred at the Plenty hatcheries, Tasmania, in February, 1933, when trout fry and yearlings died. In a report on the outbreak by the Honorary Pathologist of the Tasmanian Salmon and Freshwater Fisheries Commission it is stated that few, if any, of the deaths were caused by the parasite. The probable cause was that just prior to the outbreak the sediment at the bottom of the ponds had been stirred up by dragging bluestone bags over the bottom in an attempt to get rid of a heavy growth of weed—(Salmon and Freshwater Fisheries Commission (Tasmania). Report, June, 1933).

In July, 1933, White Spot was reported on young blackfish (*Gadopsis marmoratus*) in a private pond at Heidelberg (Melbourne). This diagnosis was later confirmed.

Numerous reports have been received of cases of White Spot on aquarium fish in Victoria and New South Wales.

The disease is also prevalent in Japan. It attacks only fish which are confined to ponds or aquaria, and is never found on those living in lakes and rivers—(Roughley, 1933).

In August, 1937, the disease was reported from Capetown, South Africa. It had been introduced with imported tropical aquarium fish. An Honorary Fishing Inspector succeeded in infecting a small indigenous fish (*Spirobranchus capensis*) with parasites from imported fish—(Cape Piscatorial Society, South Africa, 1937).

Life Cycle of the Parasite—Conditions Favouring an Outbreak of the Disease.

White Spot is caused by a ciliate protozoan parasite which is whitish in colour and visible macroscopically; the size ranges from one-half to slightly less than one millimetre in diameter. The body is round or elongate oval in shape and movement is by an active rotation brought about by the action of the cilia which are arranged regularly in rows. "The ciliate fixes itself to the skin and gradually becomes embedded in the epidermis." (Wenyon, 1926.)

The life cycle is complicated but for all practical purposes it may be divided into four phases (Fig. 1).

The disease derives its name from the appearance of the infected fish. The skin may be raised into pustules which are whitish in colour (hence the name "White Spot") over any part of the fish, body, head, fins, tail, gills, etc., in a young form, and over the gills, fins, tail or on any unscaled portion in an older individual. Within the pustules are the parasites and they remain there for a period of four to nine days or longer, the period being determined by the water temperature. The parasite passes its growing phase in this position. Numerous transverse sections have been taken through the pustule and the body wall of the fish, and although there is no doubt that the parasite does increase in size within the pustule, there is no visible evidence of any breakdown of the tissues or of the skin within which the parasites lie. Roughley (1933) states that "Occasionally these blisters are found to contain several of the parasites, which have resulted from the division of the original one into several parts." But after examining in stained preparations several hundred pustules containing very numerous individual parasites this statement cannot be supported. According to Wenyon (1926) "There is some doubt as to whether multiplication of the ciliate can take place within the pustules, for the presence of two parasites in a single pustule, as sometimes occurs, may be merely an indication of an invasion of one spot on the skin by two ciliates." In all the material examined from Ballarat the pustules have contained from several up to 40 or more individuals and the occurrence of one or two individuals in a pustule has been rare. The parasite does not lose its locomotory power within the pustule; it may be observed under a microscope to be slowly rotating if

the skin bearing the pustules is stripped from an infected fish which has just been killed. When the pustule bursts the free-swimming forms are liberated into the water; these forms may be called the *Precystic* forms and they constitute the second phase of the life cycle. Experiments have shown that these forms do not reinfect a fish, but after a few hours in the free-swimming state they settle to the bottom of the pond and there encyst; this is the third phase. The process of encystment consists of the secretion of a gelatinous membrane followed by binary fission of the individual. The number of individuals

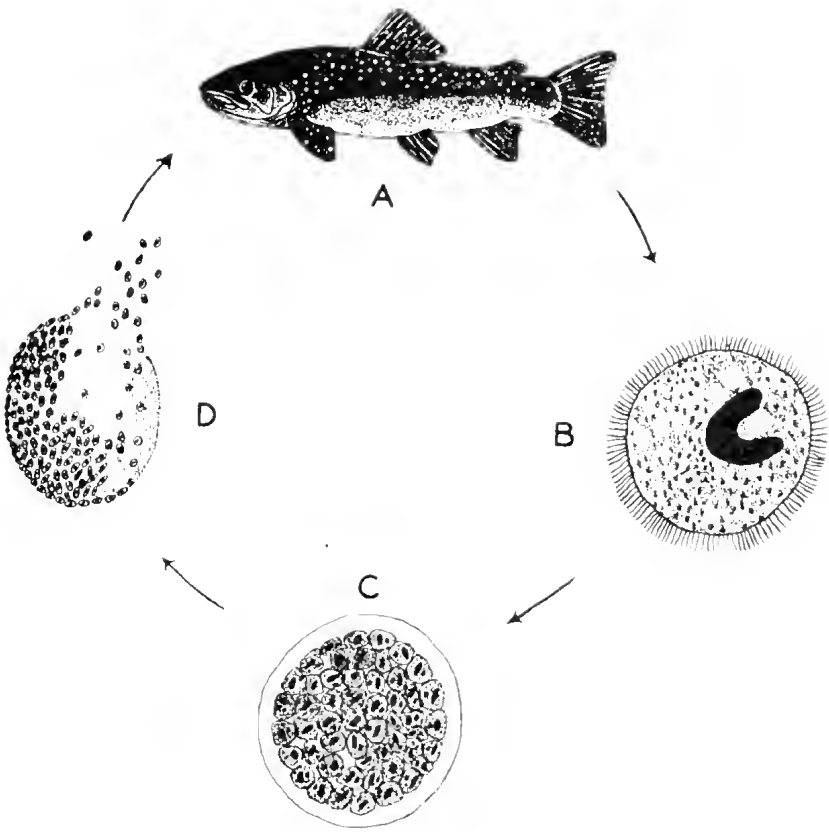

FIG. 1.—Diagrammatic representation of the life cycle of the parasite. *A*, adult parasites in pustules on a trout; *B*, parasite after leaving fish as a free-swimming pre-cystic form and about to settle to the bottom; *C*, division of the adult into many smaller individuals after formation of cyst; *D*, bursting of cyst, releasing hundreds of minute post-cystic forms of the parasite, which in turn reinfect the fish. (After Prytherch, slightly modified.)

arising from the single parasite which formed the cyst varies. Usually there are several hundred but the number may reach 2,000. Within a few hours the cyst ruptures and the new individuals which may be called the *Postcystic* forms are liberated.

These are again free-swimming and constitute the fourth phase of the life cycle. These are the forms which re-infect the fish and give rise, after a few days, to the characteristic pustules.

Thus, in the life cycle of the parasite there are two free-swimming phases and two fixed phases. All control measures must be aimed at the parasite while in any of its three stages away from the fish; this will be discussed later on. It is usually stated that the parasite is away from the host for a period of 24–36 hours, the time varying according to the temperature. Recent work, which will be dealt with more fully in a later paper, has indicated that the parasite may live for several days after it has been liberated from the cyst if the host is not available. This fact has to be taken into consideration in all control work.

Conditions which favour an outbreak of White Spot are:— (1) High water temperatures, 60°F. or greater, and (2) poor water supply.

These conditions were fulfilled in the first outbreak. Drought conditions had persisted over a considerable period; the water supply to the ponds was poor and temperatures ranging from 58–63°F. were a constant feature. In the more recent outbreak conditions were somewhat different. The water temperatures were fairly high, 62–64°F., but the water supply was excellent, sufficient being available since the commencement of the season. It may be seen that conditions favouring an outbreak were not at an optimum, but as against this, in the second outbreak, the fish infected were fry, which are more suspectible to the parasite than are yearlings.

In hatcheries the conditions favouring an outbreak are easily attained, and it is noteworthy that from hatcheries have come all the reports of serious epidemics. To my knowledge none of any importance have been reported from lakes or rivers. "In nature, on the other hand, ichthyophthiriasis is seldom observed, probably owing to the fact that under natural conditions only a very small proportion of the young parasites succeed in establishing themselves on a fish, and consequently the infections produced are so slight that they are overlooked, and the fish is unharmed" (Minchin, 1912). The possibility of an epidemic in a lake is slight and in a river even less so; in these environments, apart from the reason given by Minchin, suitable conditions are less likely to be reached.

The disease was more rapid in its effect this season (1939-40) than in the last, the size of the fish in each case again being the probable explanation.

While in Ballarat I examined a bottle of water which had been obtained, before my arrival, by dropping the bottle into an infected pond. It contained a large number of the free-swimming forms indicating the density of the parasite population.

Another point of general interest is the fact that in both outbreaks of the disease there have been a few fish which have survived in the infected ponds. This may be an indication that a few fish attain immunity.

The Source of Infection.

The distribution of the infection in the ponds during the early part of the 1939-40 season was puzzling, and at first threw no light on the probable source. The ponds at the hatcheries are in series, that is, water flows through one pond to the next. Ponds 6, 5, and 4, which are in series (see Fig. 2), and ponds 7–15, also in series, were infected. Pond 7 was the first to show infection in the outbreaks of both seasons, and the disease appeared to be most rapid in its effect in this pond on both occasions. An overflow pipe runs from pond 7 to pond 6, thus interconnecting the two series and providing the explanation for the spread of the disease through them. Ponds 17–46 form a separate unit (all not included in figure). Ponds 25 and 32, coming in series in this unit, were also infected, whilst ponds coming before and after them, and receiving the same water supply, were not infected.

The following possible sources of infection were suggested, and were examined in turn:—1. The Gong Reservoir; 2. Lake Wendouree; 3. Some source in the hatchery itself.

1. The Gong Reservoir.

This reservoir is the normal source of water for the hatcheries, but there is no evidence of the parasite coming from it. Several reservoirs form Ballarat's water supply, but the water ultimately passes through the Gong. The reservoirs are heavily stocked with English perch, and the Gong was netted, several hundred small fish being obtained. These were examined and none showed any signs of infection. A few fish were also taken from the Kirk reservoir (which supplies the Gong) and these again were clean. Evidence obtained at the hatcheries indicates that the English perch is either non-susceptible or is infected only with difficulty by *Ichthyophthirius multifiliis*. A small fish was taken from a pond in which several thousand trout had died, and in which were still large numbers of free-swimming parasites, and yet it showed no signs of infection, and was in perfect condition. Prytherch (1924) after giving a considerable list of species of fish for which the parasite has proven fatal, states that the perch, among a few others which he names, is seldom killed by the disease or affected to any noticeable degree.

2. Lake Wendouree.

Water is pumped from the lake to the hatcheries when the reservoir supply is unsatisfactory. All the water leaving the hatcheries runs into the lake, the outlet and the pump-line inlet

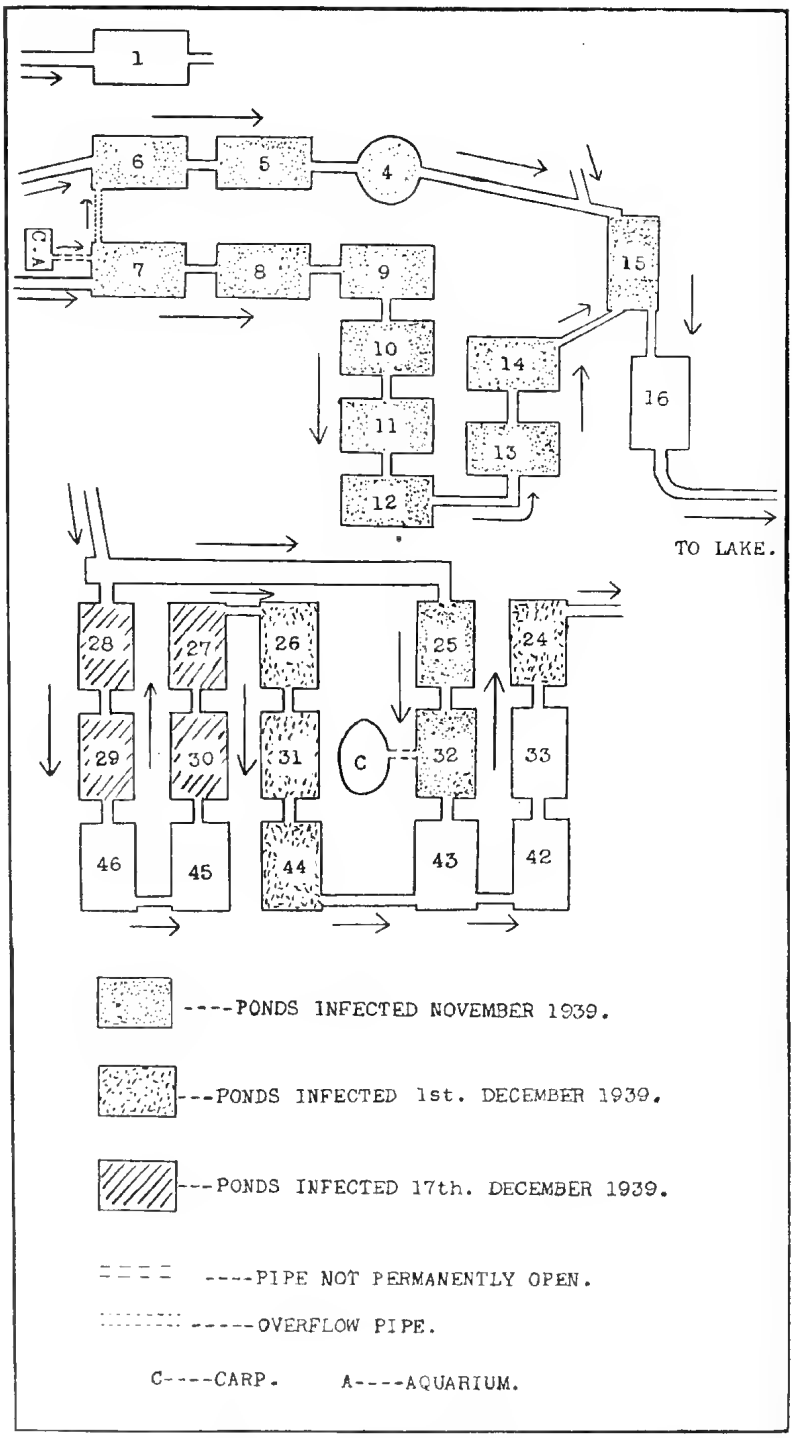

FIG. 2. Diagrammatic plan of the Ballarat hatcheries, showing only those ponds which are under discussion.

being normally some distance apart. During the 1938-39 season drought conditions prevailed and water had to be obtained from the lake. The lake level fell considerably, and to overcome this difficulty a large pit had to be dug from which water was pumped. Unfortunately, at the same time, in a further attempt to remedy the poor water supply, the outlet pipe was moved and all waste water was run into the pit. By this means water from the infected ponds ran into the pit and was carried back to the hatcheries. The water to the hatcheries first passes through concrete storage tanks before going to the ponds, and it is the usual practice to place fry in these. During the last season fish in one tank became infected. The lake must therefore have been the source of infection of this tank, even though the infection in the lake itself may have been derived from the hatcheries.

Apparently the parasite did not carry over the winter in the lake as lake water was used at one period early this season prior to the outbreak and the fish remained clean.

Unfortunately, again this season, infected water was run into the lake for two days without first being treated. Lake water has not been used since that date. Later, tests of the lake water and methods of treatment of the water running into the lake will be discussed. The inlet and outlet pipes from and to the lake are again some distance apart.

All evidence points to the fact that Lake Wendouree was infected from the hatcheries and that it is not the primary source of infection.

3. The Hatchery.

The third possible source of infection was from fish introduced into the hatchery itself. The only fish in the hatcheries were English perch, carp, and trout, both Rainbow and Brown. The perch, as already mentioned, are apparently not infected. A large aquarium of carp has been kept in the hatcheries for some years and this is only a few feet away from pond 7. These fish were examined, and in several cases were found to be carrying the parasites. The pustules were not numerous and no dead fish had been observed. Some time previous to the outbreak a tench had been placed in this aquarium and had been found dead some time later, but it was not examined. Prytherch (1924) states that ichthyophthiriasis is fatal to tench. The carp appear to act as carriers of *Ichthyophthirius multifiliis*. Once these fish were found to be infected all the evidence pointed to this aquarium being the source of infection. Pond 7 is in direct line with the aquarium and this is the pond which has been the first to show the infection on both occasions. Any heavy shower of rain will cause the aquarium to overflow into pond 7, and there is also a pipe connecting the pond and the aquarium, which has been used to empty the latter. Carp have been kept in the aquarium

for some years, but prior to the first outbreak of White Spot, fresh fish had been brought over from ornamental ponds in the adjoining Public Gardens. Japanese carp had been added to these ponds some time before this, and soon after some of these fish had been observed dead or dying. This fact had only been casually observed at the time and the fish had not been examined. As has already been mentioned, pond 6 is in direct communication with pond 7 by way of an overflow pipe, which explains how the second series became infected. Eighty thousand fry were lost early this season in these twelve ponds. Only a few carp from the ponds in the Gardens could be examined, and these showed no signs of infection. This evidence could not be taken as conclusive as these fish may not have been infected at the time, and larger numbers would have to be examined at intervals.

The explanation of the infection in ponds 25 and 32 is not quite so conclusive. Next to pond 32 (see fig. 2) is a small pond carrying carp. This carp pond is not in direct series with the main ponds, but is connected, by means of a pipe which is normally closed, to pond 32. The pipe had not been opened this season. Carp from here were examined but appeared clean. One dead fish floating on the surface of the pond was also examined, but although indications of infection were observed the fish had been dead too long to permit a definite diagnosis. The explanation of the infection in ponds 26, 31, and 44 later in the present season appears to be this: When the water level in a pond rises higher than normal, due to blockage of the outlet by silting of the wire screen across it, as occasionally occurs, the water may flow backwards through the inlet channel and thus enter other ponds. This is probably the explanation of the December 1st outbreak following on inefficient treatment of the ponds which were infected in the earlier part of the outbreak.

Although there is no direct evidence as to how the infection was carried to ponds 25 and 32 in the early part of the outbreak, there are several possible explanations.

The parasites may have been transferred by means of gear which had been used in infected ponds. This could have quite easily been done before there was any indication of the outbreak. The hatcheries are easily entered, and it is known that children interfere with the ponds in the absence of the hatcheries' staff. During one of my visits to Ballarat fish were found in ponds to which they could not have possibly moved by way of the water channels. It is possible that fry from the infected ponds could have been transferred to these ponds, which were clean in the early stages of the outbreak of disease. Birds bathe in the ponds, and the parasites may be transferred by this means. Rats also move from one pond to another. A further possible agent is the yabby (cray-fish) which is driven from the infected ponds by the salt treatment.

Control Measures.

The cheapest satisfactory means of control is by the use of sodium chloride. Laboratory tests have shown that sodium chloride and potassium permanganate destroy the parasite in its precystic, cystic and postcystic stages. The more detailed work was done with the precystic stage, using different concentrations of sodium chloride. Fifty tests were made, and the results of a number of these are given in Table II.

TABLE II.—Toxicity tests with sodium chloride.

Test.	Concentration of NaCl.	Number of Parasites Used.	Temperature.	Time of Cessation of Movement.	Remarks.
	Per cent.				
1	0·5	3	16°3 C.	.	Still alive after 35 minutes
2	0·5	2	16·3 C.	. .	
3	1·0	3	16·3°C.	. .	Actively swimming for 3·5 minutes, then movement ceased. Recovered within half an hour
4	1·0	3	16°3 C.	.	
5	1·0	6	16°3 C.	.	
6	1·0	1	18°0 C.	.	
7	1·5	1	18°0 C.	2 min. 10 sec.	No recovery
8	1·5	1	18°0°C.	4 min. 20 sec.	
9	2·0	1	18°0°C.	1 min. 50 sec.	
10	2·0	1	18°0 C.	1 min. 40 sec.	Observations made 30 minutes later. No recovery.
11	2·0	1	18°0 C.	1 min. 45 sec.	
12	2·0	1	18·0 C.	1 min. 45 sec	
13	2·0	1	18°0 C.	1 min. 20 sec	
14	2·0	3	16°3 C.	35 sec	Actively swimming for 15–25 seconds
15	2·0	3	16°3 C	40 sec	
16	3·0	4	16°3 C.	12 sec.	
17	4·0	4	16·3 C	9 sec	
18	5·0	3	16°3 C.	5 sec.	No recovery
19	8·0	5	16°5 C.	Instantaneous	
20	10·0	5	16°3 C.	Instantaneous	

The action of the sodium chloride depends on the phenomenon of osmosis, the protoplasm being observed to shrink away from the cell wall. In the case of a 1 per cent. solution this contraction takes place and movement ceases. In early experiments in which this occurred it was taken as a sign of death, and it was concluded that a 1 per cent. solution was effective. When the experiment was repeated and the parasites kept under observation for a much longer period, it was seen that they recovered within approximately 30 minutes.

All the concentrations of sodium chloride shown in Table II. are a little too high. The organisms were transferred to the salt solution by means of a fine pipette, and in each case a small drop of water was carried over, thus slightly lowering the concentration of the solution. This small discrepancy would be difficult to avoid, but it does not seriously affect the conclusions. The error is in the right direction, as these experiments were carried out to ascertain the lowest concentration of sodium chloride which would be effective in controlling the parasite

There is a point of interest in reference to tests with the postcystic form; sodium chloride gave the osmotic phenomenon mentioned above, but potassium permanganate, although rapid in its action, produced no visible osmotic change.

The parasite cannot be brought under control while on the fish; control measures must be directed at the three phases of the life cycle of the parasite when it is away from the host. Other workers have attempted control experiments while the parasite was in the pustule, but if the solution used was of a sufficient concentration to destroy the parasite it inevitably led to the death of the fish.

Numerous chemicals have been tried, and some of the reports on their actions have been contradictory. The external application of various chemicals in solution kills and removes those parasites that are about to leave the fish, as well as the smallest forms that have burrowed into the mucous coating. Prytherch (1924) records that experiments with copper sulphate, formaldehyde, sodium bicarbonate, sodium chloride and others, have been successful in killing the parasite, but have so weakened the fish that they either die or soon develop fungus growths and bacterial disease, which eventually prove fatal. He further states that for external treatment of parasitized fish the use of aluminum sulphate (alum sulphate) in solution is most satisfactory. Control work at Ballarat, using sodium chloride and potassium permanganate, has not produced any ill-effects on the fish, although, in the case of the former, the fish were treated for a period ranging from 9 to 14 days. In this case however no attempt is made to reach the parasites while on the fish but to kill them only after they have left the pustules. For this reason a weaker solution may be used and this probably explains the absence of ill-effects to the fish.

Barthélémy (1926) states that tests of many chemicals ($KMnO_4$, NaCl, $HgCl_2$, eau de Javelle, formaldehyde, toluene, chloral hydrate, camphor, pyridine, creosote, H_2O_2, thymol) proved useless, the treated fish dying before the parasite. Also he advises that the contaminated ponds be drained, exposed to sun and heat and that the hands of workmen and the tools be disinfected in milk of lime or 1 per cent. formaldehyde. Ammonia and mercurochrome solutions are suggested for ichthyophthiriasis by Mellen (1926).

Roughley (1933) discusses the use of heat as the most effective treatment for killing the parasite in all stages, including when it is on the fish. This method obviously can only be applied to aquaria. It has been found in America that the parasite will not long survive a temperature of 46° F.; and on the other hand, a temperature of from 85° F. to 90° F. also soon proves fatal. On account of the fact that the temperature of the aquarium is more easily raised than lowered, and also because a temperature of

46° F. is a critical one for many goldfish, the higher temperature has been adopted for the treatment of the disease. He then states that a 0.2 per cent. solution of acetic acid in contact with the parasite will kill it almost instantly, but if an infected fish is placed in this solution for several minutes, the parasites atttached to the fish are quite unharmed by it. Similarly he has had an infected fish in a solution containing 25 drops of 2 per cent. mercurochrome to the gallon for three days without the parasites on the fish suffering the slightest harm, although such a solution will invariably kill the parasites with which it is in contact in the course of an hour or two.

Prytherch (1924) and Barthélémy (1926) both considered that the use of a rapid flow of fresh water was the most practical method of combating the parasite. By this means the free parasites are removed as they drop off the fish, the temperature is lowered, the vigour and resistance of the host are augmented and the development of the parasite is diminished.

Fast running water, although perhaps the most satisfactory method of controlling this disease, is not applicable at the Ballarat hatcheries for two reasons: firstly the ponds are connected in series and the parasites would only be driven from one pond to the next; and secondly, all the waste water from the hatcheries is run into Lake Wendouree which is stocked with fish.

Sodium chloride is very satisfactory to use; it is cheap, it is effective in controlling the disease and it does not harm the fish in concentrations sufficient to destroy the parasites in their free living stages. Tests were made at the hatcheries as to the sodium chloride tolerance of trout fry. Time did not permit of a detailed experiment but the following results are of definite value.

TABLE III.—Tests for sodium chloride tolerance of trout fry.

Concentration of NaCl Solution.	Number of Fish.	Length of Experiment.	Temperature.	Remarks.
Per cent.				
3.5	3	1 hr. 23 min.	60° F.	Fish distressed and lying on their sides, but not dead
3.0	3	1 hr. 40 min.	60°F.	Two fish normal. One distressed
2.5	3	1 hr. 38 min.	60° F.	Two fish normal. One slightly distressed

Some of the fry at the hatcheries were in poor condition and in the tests using 2.5% and 3.0% sodium chloride solutions, the fish which showed signs of distress in each case were in a weak condition before the experiments were commenced.

The most serious difficulty met with at the hatcheries was to obtain a distribution of the salt solution throughout the ponds. These are of the following average dimensions: 50 feet long, 15 feet wide at the top, 12 feet wide at the bottom and 4 feet

deep. Each has a capacity of 12,000 gallons. The way in which the difficulty was overcome will be discussed later. The following figures (see Table IV.) give the salt concentrations at various positions in a pond. The pond had been treated with a bag of salt (approximately 180 pounds) per day for some days previously and three bags had been added three hours before the analyses were made. The salt was added by tipping it into the inlet channel so that it went into the pond in solution.

TABLE IV.—Sodium chloride analyses in treated hatchery pond.

Test.	Position in Pond from which the Water Sample was Taken.	Concentration of NaCl.
		Per cent.
1	Inlet end, bottom	1·7
2	Inlet end, 12 inches below the surface	0·3
3	Middle of pond, bottom	2·5
4	Middle of pond, 12 inches below the surface ..	0·21
5	Outlet end, bottom	3·7
6	Outlet end 12 inches below the surface	0·18
7	Two ponds beyond, in series with first pond, no individual treatment. Outlet end, bottom	2·4

These figures indicate how the solution falls to the bottom of the pond; the concentration at the bottom increasing and the concentration in the body of the water decreasing as one moves from the inlet to the outlet end of the pond. Analyses were also made in a race which was being treated and the figures were very similar to those given above.

The first outbreak of White Spot at Ballarat was noticed on the 3rd April, 1939. It was not at first diagnosed as White Spot as the fish were heavily infected with Saprolegnia. Salt treatment is also used for Saprolegnia and this was applied. After definite diagnosis of the disease as ichthyophthiriasis more careful measures were undertaken. On 11th May a report was received that the epidemic was abating and early in June the hatcheries were free of the disease. Although the surviving 20,000 yearlings were clean, the Ballarat Fish Acclimatization Society was advised not to liberate these fish in streams in the State. They were held for a time at the hatcheries, and on showing no further signs of the disease, were liberated in Lake Wendouree.

The second outbreak was first observed in the middle of November, 1939, and recurred on three occasions; December 1st, 17th, and 27th, with varying degrees of severity.

Early this season the method of applying salt treatment was to tip 3 bags of salt (approximately 12 bags to the ton) into the pond inlet daily and to leave the inlet pipe open. This would give a salt solution at the bottom of the pond of a concentration as shown in Table IV. $KMnO_4$ was also used in some ponds. A layer of concentrated salt solution at the bottom of the pond was partly effective in that it would kill the forms which had

already encysted, and also the forms dropping down to encyst, but some free-swimming forms would not come into contact with the more concentrated sodium chloride.

A visit was paid to Ballarat in the third week of November and it was realized that the methods previously used were not satisfactory. An attempt was made to combine two methods of control, viz.; the use of sodium chloride treatment and the mechanical means of running water. This was achieved by applying the salt treatment and then cutting off the water for several hours, thus permitting an effective action by the salt solution. The water was then permitted to flow and the second method of control came into force.

This method appeared to have the epidemic under control, but it broke out again on 1st December. The explanation is probably two-fold; firstly, the application of the salt was still inefficient; and, secondly, precautions were lifted too early. A point of great importance in all control work with White Spot is that the treatment must be maintained for a considerable period, for the following reasons. The parasite may be on the fish for a period of from five to fourteen days, this depending on water temperatures, as was stated in the outline of the life cycle of the parasite. Both outbreaks of disease at Ballarat have occurred at temperatures of 60° Fahrenheit or greater. Under such conditions the parasites would probably not stay on the fish for as long as fourteen days—perhaps up to nine days (the times of the appearance of the several outbreaks this season bear this out), although the period would vary. The fish may have been infected on any one of nine successive days so that on applying salt treatment for a short period, only those parasites emerging from the earlier infected fish would be destroyed. The treatment must be maintained over a period of at least ten days and preferably for a longer period if that is practicable.

In an attempt to improve the distribution of the salt solution two modifications in the method of the application of the solution were tried. In the first case the solution was made up in the pump well which supplied the ponds, and in the second, the form of the inlet pipe was altered. The inlet pipe is normally just a little lower than the level of the top of the pond and the water enters in a single jet. An inlet pipe based on a form used in the United States of America was now introduced (see fig. 3). The pipe now went to a depth of 2 to 3 feet into the water and the end of the pipe was plugged. Several holes were bored into the pipe and by this means a greater distribution of the inflowing water was obtained throughout the depth of the pond.

The circulation of the salt solution was still not satisfactory and another outbreak of the disease occurred in different ponds on the 17th December. A further visit was paid to Ballarat and

another attempt was made to surmount the difficulty of circulation. The inlet pipe which had been previously modified was

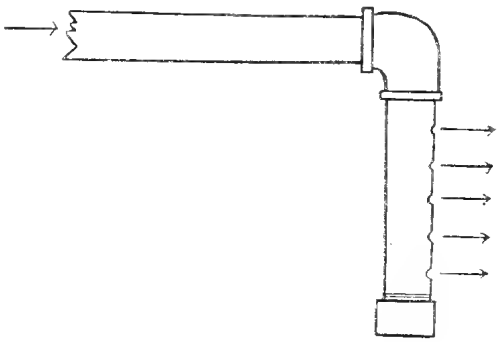

Fig. 3.—Modified form of inlet pipe for hatchery pond.

elaborated still more (see fig. 4). The pipe was lengthened and again holes were bored at intervals. The end was plugged and the pipe was now laid along the bottom over the full length of the pond.

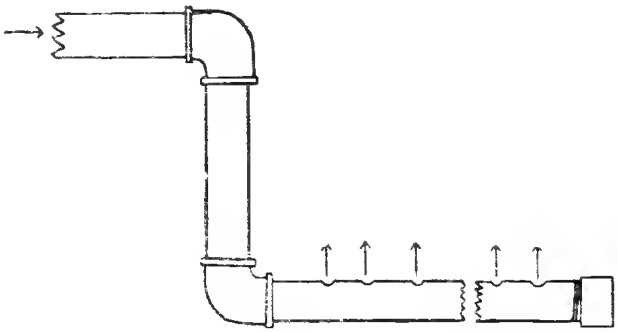

Fig. 4.—Second modified form of inlet pipe for hatchery pond.

Considerable convection currents were obtained by this means and the circulation was appreciably increased. All the infected fish in the hatchery ponds were isolated in a single pond supplied with a pipe of this type. Treatment was first commenced by using 6 bags of salt per day, and this was continued for nine days. The quantity of salt was then reduced to 4 bags per day, and the treatment was carried on for another four days. On the 27th December it was reported that the pond was clean and that there were no further losses. Salt treatment was persisted with and on the 12th January, 1940, the fish were still free of the parasite.

Many of the clean fish, that is fish which had not previously been infected, had been isolated in the hatching boxes. These boxes have no connexion with the ponds and no infection could by any means reach them from the ponds by way of the water system. On the 25th December it was noticed that these fish were infected with White Spot. The only possible explanation is that gear which had been contaminated from infected ponds had been used in the hatching boxes. The warmer weather would give more favorable conditions for the outbreak. These fish also were clean on the 12th January, eighteen days after the infection was first observed, having responded to treatment with sodium chloride. This period is longer than the necessary quarantine period so a favorable conclusion may be drawn. A further report was received from Ballarat on the 23rd January stating that the disease had been brought completely under control, and that the type of pond inlet pipe illustrated in Fig. 4 had proved to be very satisfactory.

As has already been mentioned, sodium chloride is a means of control both for White Spot and a disease caused by the fungus Saprolegnia sp. Saprolegnia played an important role in the White Spot outbreak of the 1938-39 season. As far as is known it cannot attack a healthy fish and there must be some injury for the fungus to become established. The pustules of ichthyophthiriasis supply the necessary injured surface. Following on the first outbreak the fungus was very wide spread and must have been responsible in part for the death of the fish. That the protozoan parasite can itself cause the death of the fish has been well illustrated in the outbreak late in 1939, when the hatcheries were practically free of fungus.

There has been some doubt as to whether the cyst of *Ichthyophthirius multifiliis* can withstand desiccation, and as this is a point of great practical importance, tests were carried out. Cysts were isolated and placed in drops of water and were then allowed to dry off in the air. They were moistened again on two successive days and kept under observation. It was seen that the parasite cannot survive in the absence of water.

Recommendations for the Diagnosis and Treatment of White Spot.

1. If fish are dying in numbers and are showing the symptoms of White Spot, place a few of the dead fish in a tube of water. If the fish are infected with *Ichthyophthirius multifiliis* the parasites will emerge from the pustules within a few hours and can be seen moving around in the water. These parasites are large for Protozoa and can be distinguished macroscopically as

small white roundish objects moving slowly around. This test is applicable to hatcheries where laboratory equipment is generally lacking.

2. Isolate infected ponds by cutting off the water and treat with sodium chloride, as suggested in the discussion on control methods. It is of great importance that the treatment be maintained for a period of from ten to fourteen days, preferably longer if it is possible.

3. After treatment of the infected ponds for this period examine samples of the water at intervals for the free swimming parasites, and if they are still present give further salt treatment. Empty the ponds and allow them to dry out before using again. A further precaution would be to spray the sides and bottom of the empty pond with a concentrated solution of sodium chloride.

4. If waste water from infected ponds does not run into the drainage system but into a lake (as is the case at Ballarat), it must first be treated with sodium chloride. If the waste water leaves the hatchery by way of a race, it is advisable to break down the rate of flow to permit of more effective treatment. This may be done by placing bags in the race, these acting as a baffle.

5. Sterilize all gear such as nets, dipping nets, etc., after use in an infected pond. This may be done by dipping the gear in a concentrated solution of sodium chloride. This precaution prevents the transfer of parasites from one pond to another.

6. Destroy all carp in the hatcheries and sterilize the ponds and aquaria which contained them. In future no carp should be brought into the hatcheries; this statement applies to all fish hatcheries. As far as is known, carp is the original host of the parasite, and in many cases it acts only as a carrier of the disease and suffers no ill-effects.

7. If it is possible, destroy all carp in the vicinity of the hatcheries. In the case of the Ballarat hatcheries this applies to the fish in the adjoining Public Gardens.

8. If the source of the water supply is suspected of carrying infected fish it may be tested in the following way. Pump the water into isolated ponds containing trout fry or yearlings and keep these ponds under observation for the appearance of the disease. If possible, this should be done for a period of fourteen days, and if it is practicable, several ponds should be used, filling them successively at intervals of two days. By this means the period of observation may be extended over a period of from three to four weeks.

9. As the efficiency of the salt treatment depends on the complete circulation of the sodium chloride solution throughout the pond, it is essential that a satisfactory method of water circulation

be devised. As in most cases hatchery ponds are of a considerable size, it is suggested that an inlet pipe of the type illustrated in Fig. 4 be installed. In the absence of disease this type of pipe would still be of service, as the improved water circulation would benefit the fish.

10. It is suggested that a quarantine be applied to all exotic aquarium fish coming into the Commonwealth. The fish should be isolated for a period of three weeks, and if within that time there is no appearance of the disease, they could be declared as free of Ichthyophthiriasis. This measure, while assisting to keep this disease in check, would not greatly interfere with private aquarium owners; valuable fish would still be obtainable, while in all probability the rubbish would be kept out.

Summary.

Outbreaks of White Spot disease of fish (caused by a ciliate protozoan parasite, *Ichthyophthirius multifiliis* Fouquet) have occurred at the Ballarat Hatcheries in two successive seasons; yearlings being lost late in the 1938-39 season and fry early in the 1939-40 season.

The life cycle of the parasite is discussed, as it has important bearing on the methods of control.

Conditions favouring an outbreak of the disease in epidemic proportions are considered.

The source of infection is found to be from carp which had been introduced into the hatcheries prior to the first outbreak. These fish had been in contact with Japanese carp which are probably the source of the disease in this country.

Control measures are discussed, the use of sodium chloride being dealt with at length.

Recommendations are made as to treatment of and safeguards against this disease.

Acknowledgments.

In conclusion I would like to thank Mr. J. A. Thomas, of Ballarat, for the hospitality he extended me on my visits to Ballarat; Mr. G. W. Cornell, of the Ballarat School of Mines, for information with which he supplied me and for his valued assistance in determining sodium chloride concentrations; and to Mr. H. Coulter, of the Hatcheries, for his assistance.

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Art. III.—*The Place of the Genus* Styliolina *in the Palaeozoic Palaeontology and Stratigraphy of Victoria.*

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Summary.

Bibliography.

Historical.

In 1904 Chapman (1904) described specimens of *Styliolina* from the Upper Yarra District as "*Styliola fissurella*, J. Hall, var. *multistriata*, var. nov." and figured a specimen which is now in the National Museum, Melbourne, as the type of the variety.

In 1912 Chapman (1912), describing fossils for the Geological Survey of Victoria, recorded "*Styliola fissurella*, J. Hall, var. *multistriata*, Chapm." from shale on the spur between Jordan River and B.B. Creek.

The following year Chapman (1913) referred the *Pancnka-Styliola* beds to a new horizon, which he termed "Tanjilian." He considered this stage to be above the Yeringian series, and to be Upper Ludlow or Lower Devonian in age.

Chapman (1914) recorded the occurrence of "*Styliola fissurella* Hall, var. *multistriata* Chapm." from Howe's Creek Quarry, Loyola, near Mansfield.

Whitelaw (1916) described the geology of the Wood's Point District, and recorded the presence there of *Styliola fissurella* var. *multistriata*.

Kitson (1917) reported from the Powlett Plains District, South Gippsland, the presence in shales of pteropods like those of the Upper Yarra District. These were obtained from a bore at a depth of 660 feet, and were later identified by Chapman (1924) as *Styliola fissurella*, var. *multistriata*.

Junner (1920) grouped the beds of the Walhalla-Wood's Point District which contain *Styliolina* under the name "Panenka Beds" and gave their stratigraphical position as underlying the basal grit of the Walhalla Beds. Both the Panenka beds and the Walhalla beds he classified as "Yeringian (Upper Silurian)."

Chapman (1924) amplified his 1913 hypothesis of a Tanjilian stage above the Yeringian one, and after a discussion of the flora and fauna of the strata, expressed the view that they were almost certainly Devonian in age.

Skeats (1928) showed that the *Panenka-Styliola* beds are below the western basal grits (Yeringian) of the Walhalla Synclinorium, concluding that the Jordan River (Tanjilian) beds are therefore older and not younger than the Yeringian beds (as Chapman had asserted). Skeats proposed the discontinuance of the term "Tanjilian." He also recorded the occurrence of *Styliola* on the Thomson River.

Edwards (1932), when describing the rocks of the Warburton District, referred to the presence of *Styliola* in the Upper Yarra District.

Chapman and Thomas (1935), in a systematic description of the Silurian rocks of Victoria, supported the findings of Skeats (1928), but omitted the Tanjilian series from the sequence (p. 107).

Thomas (1939), in outlining the structure of the Palaeozoic rocks of Victoria, claimed that the *Panenka-Orthoceras-Styliola* association constitutes a reliable marker horizon. He mapped these beds with the Yeringian series.

In 1940 the author (1940) recorded *Styliolina* from Coldstream, a locality in the type Yeringian area.

Palaeontological.

History of the Genus Styliolina.

Until the year 1864, the fossils now accommodated in the genus *Styliolina* were called *Tentaculites*. In that year Professor Ludwig (1864) referred these smooth "Tentaculites" to the genus *Styliola* of Leseur. In the succeeding years Richter (*vide* Barrande, 1867), Barrande (1867), Hall (1879), and others referred these shells without annulations to *Styliola*, and so the genus became established in Palaeozoic palaeontology. In 1884 Karpinsky (1884) gave reasons for believing that the Palaeozoic Styliolae are distinct from the more recent forms, and he suggested for the former the name *Styliolina*. "*Styliolina* is distinguished from *Styliola* by the form of the embryonal bulb, the lack of longitudinal furrows and thorn-like processes about the stoma and the presence of longitudinal incised lines" (Clarke, 1885). This distinction is now generally accepted among palaeontologists.

Zoological Relationships of Styliolina and Tentaculites.

The relationship of these genera, and the classification of *Tentaculites* as a Pteropod, have been called in question by some (*vide* Reed, 1906, p. 124; Zittel-Eastman 1913, p. 569). Referring to the bulbous apex of *Tentaculites gracilistriatus*, Hall (1879, p. 174) wrote, "This minute bulb is so precisely like that . . . in recent forms of *Styliola*, that I cannot doubt that it is of precisely similar character and significance." The same author (p. 177) quoted Barrande as saying "These two genera seem then to disappear at the same time, which renders their reciprocal relations more marked." The possession of a bulbous protoconch by both these genera is an important structural link. Both these forms are pelagic and their environmental association should be noted. Shells of like proportions belonging to these genera, and in similarly immense numbers, are found associated in the same beds even when other fossils are apparently absent. We may infer that, because they thrived in the same environment even when other forms of life were reduced, that they were physiologically similar.

The genus *Tentaculites* is distinguished from that of *Styliolina* by its possession of annulations on the shell. The two genera, however, are not always easily separated. There are intermediate forms difficult of classification, such as *T. intermedius* Barrande (see also *Styliolina fissurella* var. *obsolescens* Hall).

Determination of the Victorian Form.

Styliolina is a genus difficult to divide into species satisfactorily. Barrande writes, "As a result of the diminutiveness of the forms named and the almost complete absence of ornament on their surface, one finds the chief difficulty is to establish their specific independence." Hall agrees (1879, p. 175). Because these shells have no specialized structure, almost the only data for specific separation are:—

1. Proportions of the shell.
2. Ornament on the shell.
3. Size of the shell.

1. The proportions of the shell seem to provide one of the surest means of distinguishing different species. Chiefly on this basis, for instance, Hall established his *Styliola obtusa* and *S. fissurella* var. *strigata* (Hall, 1879).

2. The ornament on the shell is sometimes significant, but generally is a rather variable character. Smooth, transversely striate, longitudinally striate, and both transversely and longitudinally striate forms are found in the same species, viz., *S. fissurella*.

The longitudinal fissure so often observed in *Styliolina* and the accompanying *Tentaculites* is commonly explained as a fracture or indentation produced by pressure in the rock. This explanation has been given by Hall (1879), Swartz and Prouty (1923, p. 490), and Prosser and Kindle (1913, p. 300). The shell-substance of *Styliolina* is very thin and therefore some degree of collapse is to be anticipated. It is noticeable that the fractures are usually in the centre of the shell as they appear on the surface of the rock. This can be explained as due to pressure operating vertically to the bedding plane. As often as not the fracture is on the upper surface of the shell. If this depression were natural, then it would be expected that the flatter, depressed side would come to rest on the sea-floor with the rounded side uppermost, and very rarely vice-versa. Some shells have the fracture on both upper and lower surfaces. Specimens occur in which the shell has not collapsed. The author has made sections of such a specimen from Muddy Creek, and observed a fully circular cross-section. (cf. Ludwig, 1864, "von rundem—nicht eckigem—Querschnitt.") Hall (1879), after referring to the fissure observed in the *Styliolina* shells collected from the shales, wrote, "When occurring in the calcareous bands, this feature is not characteristic."

3. *Styliolina* is usually a minute shell from two to three millimetres long, but a large form (about 45 mm. long) is recorded from the Middle Niagaran of America (Swartz and Prouty, 1923). In this case, size is a specific character. It is also a specific character of *S. spica* Hall (*vide* Grabau, 1889).

The specimens of *Styliolina* so far collected in Victoria apparently all belong to the same species. They agree in proportions, ornament (where present) and size with *S. fissurella* (Hall), a form having a very wide geographical distribution in North America. Chapman (1904) determined specimens of *Styliolina* from the Upper Yarra as *S. fissurella*, but regarded them as differing in a varietal manner from that species, and called them *S. fissurella* var. *multistriata*. He wrote: "The Victorian specimens cannot be separated specifically from Hall's *S. fissurella*, but differ from it in a varietal manner, by having the surface marked with very fine and regular transverse lines of growth. The American specimens are very variable as to ornament, but they do not show so constant a character in the lineation of the shell as do our specimens." The present writer doubts the validity of this variety. It should be noted that transverse striae on North American specimens of *S. fissurella* are common and characteristic, as the following quotations show:—

> "Annulated above and smooth near base." (Hall, 1843).
> "Surface often smooth and without any visible ornamentation so far as can be determined; or with fine striae of growth, which are unequally developed on different parts

of the shell; also with fine longitudinal striae, which may be present with or without transverse striae." (Hall, 1879, p. 178).

"Transverse and sometimes longitudinal striae." (Grabau, 1899).

"Surface smooth, marked only with fine lines of growth." (Grabau and Shimer, 1909).

"The Maryland specimens are smooth impressions except that the larger ones show very faint remains of transverse striae." (Prosser and Kindle, 1913).

Some of Hall's figures of transversely striated specimens of *S. fissurella* (*vide* Hall, 1879, Plate XXXI.A, figs. 4, 8, 10, 13, 15) are strikingly like our Victoria form. Chapman's figure (1904, Plate XXXI., fig. 4) shows the striations as very closely approximated to one another. The photomicrographs (Plate IV., figs. 2 and 3) accompanying this paper show that to be inaccurate. The spacing of the striae is comparable with that seen on Hall's Figs. 8, 13 and 15.

Hall describes a number of varieties of *S. fissurella*, but makes no variety dependable on ornament alone because this is so variable a feature. The present writer regards the striations on our Victorian specimens as but growth lines and of no special morphological significance.

Chapman (1904) regarded the transverse striations as a constant character. However, large numbers of specimens, collected from numerous localities, were examined, and were found to possess smooth more often than transversely striate surfaces. In view of the foregoing considerations, it is suggested that the variety lapse into synonymy with the species.

Hall (1879, p. 177) remarks that some specimens of *S. fissurella* are scarcely distinguishable from *S. clavulus* (Barrande). The Victorian forms of *S. fissurella* are mostly not so slender as the specimen of *S. clavulus* figured by Barrande (1867, Plate 14, figs. 28, 29) and taper fairly evenly to the apex, which the latter species does not do. Further, *S. clavulus* always has a smooth test, while the Victorian specimens sometimes have transverse striae. Nevertheless, like Hall, the author has observed specimens of *S. fissurella* which are difficult to distinguish from *S. clavulus*.

Faunal Associations.

Throughout the world *Styliolina* is usually accompanied by *Tentaculites* of like size and proportions, and in similarly large numbers. In U.S.A. the associated species with *S. fissurella* is generally *T. gracilistriatus* (Hall, 1879, etc.). In Canada *T. gracilistriatus*, *T. bellulus*, and *T. attenuatus* are recorded as in association with *S. fissurella* (Stauffer, 1915; Dyer, 1931; Fritz, 1939; etc.). In Cornwall *Tentaculites* sp. is recorded with

Styliolina sp. (Fox, 1900; 1905; etc.). In Bohemia *T. elegans* occurs along with *S. clavulus* (See Barrande, 1867, for Bohemia and other European areas). In the Northern Shan States *Styliolina* cf. *laevis* is associated with *T. elegans* and *T.* cf. *ornatus*. In Victoria *T. matlockiensis* Chapman is commonly found with *S. fissurella*. In addition *Panenka gippslandica* McCoy and various orthoceracones are characteristic faunal associates of *Styliolina* here in Victoria. Plant remains are also very common in the series, although they do not actually occur in the same bed as *Styliolina* in any locality, as far as is known.

Emended Description of *Tentaculites matlockiensis* Chapman.

The fossil described by Chapman (1904) as *Tentaculites matlockiensis* is a poorly preserved specimen, and the collection of well-preserved material now makes an emended description desirable. A hypotype (from Muddy Creek, Wood's Point Road, 11 miles east of Warburton) is now presented (Plate IV., fig. 5). The specimen is in the National Museum, Melbourne (Reg. No. 14089). Chapman's original description was as follows:—

"Shell conical, tapering, but broader at the open end than is usual in this genus. Shell substance thin, as in Styliola, but having distinct annuli, as in the typical forms of Tentaculites. Apical portion bulbous, sometimes apiculate, and occasionally with an overhanging flange. Margin of the orifice undulate, and with a vertical slit or sinus in a line with the median depression of the shell-surface. A transverse section of the shell shows it to be thinner in the neighbourhood of this depression, and the example figured has a tubular enclosure which has the appearance of a small siphuncle or ventral canal. The proximity of this tube to the wall of the shell seems, however, to be unfavourable to the idea of its relationship to the Cephalopoda, to which it might otherwise point. On the other hand examples are not unknown where a smaller shell is found enclosed in an adult specimen, and from the relative diameter of our section, the slice was apparently taken across the shell, not far from its apical end, where the enclosed shell would have a much smaller diameter. The first third of the shell is generally smooth, afterwards becoming annulated with thin salient ridges, the intercostal spaces being concave. The annuli cease near the marginal extremity, and the shell-surface bears numerous, vertical, superficial wrinklings pointing to an affinity with the vertically striated species of the genus."

Description of hypotype: Shell minute, acicular cone, tapering from the stoma to the apex rather slowly for the first third of length of shell, then more rapidly for the remainder. Circular in cross-section, thin-shelled (so that the specimens are usually crushed, displaying a fissure similar to that in the accompanying *Styliolina* shells). About 70 rounded annulations which are wider than the interspaces so that the mould shows thin ridges between the troughs formed by the annulations. Annulations more crowded at apical end than at stomatic end.

Comment: The margin of the orifice is not undulate as originally described, the unevenness of the margin being due to the incompleteness of the specimen. The type (Plate IV., fig. 1) is apparently an internal cast—hence the smoothness of part of

the shell and the faintness of the annulations. Comparison may be made with the photomicrograph reproduced with this paper (Plate IV., fig. 4). The stomatic end of this specimen shows the internal cast, while the breaking away of the cast reveals the external mould at the apex. On the same slab as the type specimen and on another slab on the same plaque in the National Museum there are impressions of shell-fragments showing clearly the typical ornament of the species as referred to in the emended description. There are also poorly preserved specimens of *Styliolina fissurella*.

Tentaculites matlockiensis is of similar size and proportions to *S. fissurella* and it occurs in similarly large numbers with it. The species is comparable with *T. elegans* Barrande in size and proportions. However, *T. matlockiensis* has much more numerous annulations, and the characteristic longitudinal striation of Barrande's species is absent. The more numerous annulations on a shell of similar size means also that the interspaces are different in the Victorian species from those of the Bohemian species. Besides its occurrence in Europe, *T. elegans* is known from Burma (Reed, 1906, pp. 124-125).

T. matlockiensis may also be compared with *T. gracilistriatus* Hall which is a frequent associate of *S. fissurella* in North America. In *T. gracilistriatus* the annulations are subequidistant, those towards the apex being more distant and more subdued. In *T. matlockiensis* the annulations are crowded near the apical end and are not subdued. *T. gracilistriatus* has the apical portion of the shell smooth and is ornamented with longitudinal striations. *T. matlockiensis* has annulations right to the apex, and no longitudinal striations have been observed.

T. bellulus Hall is another North American species which occurs with *S. fissurella* in that continent. It differs from Chapman's species in being much more attenuate, in having a smooth apical portion, and in possessing acute annulations.

Stratigraphical.

Occurrence and Range of *Styliolina* beyond Victoria.

Styliolina occurs in rocks of both Silurian and Devonian ages. A large form occurs in the Middle Niagaran of Maryland (Swartz and Prouty, 1923). La Touche (1913) records the genus from the Silurian of the Northern Shan States. Mansuy (1916, 1919) records it from the Devonian of French Indo-China. *Styliolina* occurs in the Devonian of United States of America (Hall, 1879, etc.), Canada (Dyer, 1931; Fritz, 1939; etc.), England (Fox, 1900, 1905, etc.), and the continent of Europe (Barrande, 1867, etc.).

Occurence of *Styliolina* in Victoria.

Styliolina fissurella (Hall) is known from the following localities in Victoria:

1. Railway cutting, Coldstream (Gill, 1940). Chapman (1924, p. 318) has noted scattered specimens in the Lilydale shales. The writer has collected such from Melbourne Hill and Mitchell's Paddock in that same area. *Tentaculites matlockiensis* was also found in the Mitchell's Paddock outcrop. The Coldstream locality, however, is a definite *Styliolina* band with the specimens in immense numbers.

2. Warburton Highway, Killara, in a cutting about $\frac{1}{4}$ mile east of the turn-off to Killara Railway Station. New locality.

3. "Mouth of Starvation Creek" (Chapman, 1904).

4. Muddy Creek, in a road cutting on the Wood's Point road on the west side of the creek. New locality.

5. Between Muddy Creek and McMahon's Creek Village. New locality.

6. McMahon's Creek (Chapman, 1904). This locality was on a steam tram line now out of use. The Wood's Point road was not then constructed.

7. Cutting on Wood's Point road a short distance east of the quarry containing plant remains at Yankee Jim Creek. New locality. This is near the site of the former village of Reefton.

8. Eighteen-mile Quarry (i.e., east of McVeigh's), Yarra Track (Thomas, 1939).

9. Spur between Jordan River and B.B. Creek (Chapman, 1912; Whitelaw, 1916).

10. Mt. Matlock. New recording.

11. Near Platina (Chapman, 1924).

12. Erica District (Chapman, 1924). Mr. Baragwanath informs me that this locality is on the Walhalla-Erica railway line about 3 miles east of Erica, near Cooper's Creek.

13. Thompson River, near Machinery Spur. The locality is 5 chains east of the Thompson River and 20 chains south of the Quarter Sheet boundary (Skeats, 1928).

14. Howe's Creek Quarry, Loyola (Chapman, 1914).

15. Yea-Alexandra District. Dr. Harris and Messrs. Keble and Thomas found *Styliolina* in this area, but the occurrence has not been previously recorded.

16. Powlett River bore (Kitson, 1917; Chapman, 1924).

17. West of Yankee Jim Creek.

Stratigraphical Range of *Styliolina* in Victoria.

Styliolina fissurella is very widely distributed in the North American continent, and its presence in Victoria supports the theory of a Palaeozoic Pacific Ocean postulated by Ruedemann (1911; 1927; 1934, p. 22) and others. In addition to this fossil there are many other species in the Victorian "Silurian" (part of the so-called Silurian no doubt belongs to the Devonian) which are the same as, or comparable with, those found in the North American Silurian and Devonian formations. The following have been noted:—

Actinopteria boydi (Conrad).
Anoplia sp.
Atrypa aspera (Schlotheim).
A. hystrix Hall.
A. reticularis (Linnaeus).
Atrypina imbricata (Sowerby).
Bythotrephis gracilis Hall.
B. tenuis Hall.
Calymene blumenbachi (Brongniart).
C. nodulosa (Shirley) = *C. tuberculosa* Salter non Dalman.
Coelospira hemispherica (Sowerby).
Cyclocerας bullatum (Sowerby).
Cyrtinopsis perlamellosus (Hall).
"*Dalmanella*" *testudinaria* (Dalman).
Delthyris crispa (Hisinger).
D. sulcatus (Hisinger).
Edmondia perobliqua Chapman cf. *E. obliqua* Hall.
Eospirifer plicatellus (Linnaeus).
Favosites basaltica Goldfuss.
F. gothlandicus Lamarck.
Goniophora glaucus Hall.
Grammysia arcuta Conrad.
G. plena Hall.
Haliserites dechenianus Göppert.
Heliolites interstinctus Goldfuss.
Leiopteria ozeeni Hall.
Leptaena rhomboidalis (Wilckens).
Lingula lewisi Sowerby.
Modiolopsis nasuta Conrad.
Monograptus dubius (Suess).
M. priodon (Bronn).
Nucula lamellata Hall.
N. lirata Conrad.
N. opima Hall.
Palaeantina solenoides Hall.
Palaeoneilo brevis Hall.
P. constricta Conrad.
P. tenuistriata Hall.
Parmorthis elegantula (Dalman).
Plagiorhyncha decemplicata (Sowerby).
Platyceras erectum Hall.
Plectambonites transversalis Wahlenburg.
Retiolites (*Cladiograptus*) *geinitzianus* Barrande.
Rhynchotreta cuneata Dalman.
Stromatoporella granulata Nicholson.
Tancrediopsis spectabilis (Chapman) cf. *T. altistriata* McLearn.
Uncinulus stricklandi Sowerby.

This list can be extended when the faunas of other Australian States and of New Zealand are considered (Vide De Koninck, 1898; Shearsby, 1911; Allan, 1935; Shirley, 1938; Gill, 1939, etc.). Thus *Styliolina fissurella* is only one of a large group of fossils which demonstrates the faunal connexion between the Siluro-Devonian beds of Australasia and those of North America.

In North America *Styliolina fissurella* occurs in strata of Middle and Upper Devonian age. In Victoria it occurs in beds of much earlier age, having been found interbedded with *Monograptus* (Skeats, 1928, p. 229). It is interesting to compare a similar occurrence in the Northern Shan States (La Touche, 1913), where *Styliolina* cf. *laevis* is associated with *Monograptus riccartonensis*. In Victoria, *Styliolina* has also been found in the type Yeringian area (Gill, 1940) on approximately the same strike as the limestone of Cave Hill to which Ripper (1938) and Hill (1939) have attributed a Devonian age. Thus *Styliolina* has quite a long time-range in Australia as it has in North America, but in a lower geological sequence. The early appearance of *S. fissurella* in Victoria, compared with its occurrence in North America, is a character observed in some other Victorian forms. Vascular land plants occur associated with *Monograptus* (Lang and Cookson, 1935). Some brachiopods (e.g., *Anoplia*) occur earlier here than they do elsewhere. These facts invite the theory that for some forms at least Australia was a Palaeozoic evolutional distributing centre (cf. Reed, 1906, p. 179; Chapman, 1908, p. 8).

When first dividing the "Silurian" of Victoria into Melbournian and Yeringian series, Gregory (1903) included the *Panenka-Styliolina* beds of the Upper Yarra district in his Melbournian division. Chapman (1914, 1924) included these strata in his Tanjilian series, which he regarded as younger than the Yeringian and probably Devonian in age. Skeats (1928) has shown the Tanjilian series to be older and not younger than the Yeringian series. Chapman and Thomas (1935) agreed with Skeats, but omitted the Tanjilian series from the "Silurian" sequence, apparently including it with the Yeringian series. Thomas (1939), in mapping the structure of the Lower Palaeozoic rocks, included the *Styliolina* beds with the Yeringian. He also stated that the *Styliolina-Panenka-Orthoceras* association provides a good marker horizon. Chapman (1913, p. 212) described his Tanjilian series as follows: "This series comprises the Panenka shales of Mt. Matlock, and Reefton, near Warburton. In the Walhalla District the Panenka shales of the Jordan River series lie on the Walhalla geosynclinal, and abut on Upper Ordovician graptolite beds. . . . Should the stratigraphical evidence prove this to belong to a distinct stage in Victoria, I would suggest the term Tanjilian, since the Panenka shales are well developed in the district of the Tanjil River, Gippsland."

There is here no clear indication of which outcrop is to be regarded as the type area of the Tanjilian, unless it be that from which the name is derived. The only locality in the Tanjil River area is that mentioned by McCoy (1879), viz., Russell's Creek, which is a tributary of the Tanjil River. McCoy gives that place as a locality at which *Panenka gippslandica* is "common." Mr. Baragwanath, the director of the Geological Survey of Victoria, is of the opinion that the specimens concerned came, in fact, from McMahon's Creek. The Russell's Creek Mining District reaches as far as the headwaters of McMahon's Creek. Murray (1916) claimed to have collected the specimens referred to by McCoy, but he does not mention them in his two earlier reports (1876, 1880), and when he was making the re-survey described in his 1916 report, Mr. Baragwanath inquired about the Russell's Creek locality, but Mr. Murray was unable to say where it was. The fossils are recorded (Murray, 1916) as coming from a tunnel, but no tunnel has been located on Russell's Creek. The nearest known tunnel is one under the basalt about 1½ miles south of where Russell's Creek joins the Tanjil River. This is described in Progress Report No. 6 of the Geological Survey of Victoria. Further, it is to be noted that *Styliolina* has not yet been collected from there (*Contra* Chapman and Thomas, 1935, p. 108). Furthermore, the "Tanjilian" as re-defined in this paper is not co-extensive with the series described by Chapman (the Monograptus Beds are removed), and the name "Tanjilian" itself is associated with an error of sequence. The cumulative force of the foregoing considerations seem to provide good practical grounds for adopting Skeat's suggestion of abandoning the name "Tanjilian." I propose therefore that the name "Jordanian" be substituted, as beds of the *Panenka-Styliolina* association have been fully proved and accurately mapped in the Jordan River area (Whitelaw, 1916; Jutner, 1920; Baragwanath, 1925; Skeats, 1928). I propose also that the locality "between Jordan River and B.B. Creek" be the type locality for the Jordanian. As already stated, I do not propose that the Jordanian be co-extensive with the Tanjilian of Chapman. Jutner (1920), dealing with the beds which Chapman called Tanjilian, separated the *Monograptus* beds from the *Panenka* beds, referring the former to the Melbournian series and the latter to the Yeringian series. The distinction is a sound one. Whitelaw (1916), in the caption of his map of the Wood's Point District, distinguished between—

1. Yellow silky mudstones with *Panenka*, etc.
2. Black slates with *Monograptus* sp.

Hall (1906, 1907) has recorded the following graptolites from the beds called Tanjilian by Chapman:—

Monograptus cf. *crenulatus*.
M. dubius.
M. cf. *jackeli*.
M. sp. (*colonus* type).

Chapman (1924) included these doubtfully in his list of Tanjilian fossils. Chapman and Thomas (1935) have suggested that they point to a Melbournian age. Recently, Harris and Thomas (1939) have identified the following forms from the Yarra Track:—

Monograptus uncinatus var. *orbatus.*
M. uncinatus var. *micropoma.*
M. vomerinus.
M. vomerinus var. *crenulatus.*

M. dubius and *M. colonus* are known from the Melbournian of Melbourne itself (Thomas and Keble, 1933). The two varieties of *M. uncinatus* have both been recorded from the Melbournian beds at Heathcote (Harris and Thomas, 1937). *M.* cf. *vomerinus* has been collected from beds of Melbournian age near Yass, New South Wales (Sherrard and Keble, 1937). *M. jackeli* and *M. vomerinus* var. *crenulatus* are not known from any other locality in Australasia (vide Keble and Benson, 1939). The foregoing evidence persuades me that some at least of the *Monograptus* beds are Melbournian. The *Monograptus* beds appear to be conformable with the Mt. Easton Ordovician strata and so Keilorian beds are to be expected between the Ordovician and Melbournian (as re-defined by Thomas and Keble in 1933). Chapman and Thomas (1935) record Keilorian graptolites "including *Monograptus aplini* and *Stomatograptus australis*" from the Jordan River series.

I propose, therefore, that the "Silurian" succession in Victoria be recognized as follows:—

4. Yeringian (youngest).
3. Jordanian.
2. Melbournian.
1. Keilorian.

It will be observed that the Jordanian series is more restricted than the Tanjilian series of Chapman.

Besides having a characteristic palaeontology, the Jordanian series has a characteristic lithology. The sediments consist mainly of shales (many of which are finely laminated) and of massive felspathic sandstones. Neither of these latter types of rock can be considered characteristic of either the Melbournian or the Yeringian series. They are absent from the Melbournian and Yeringian type areas. Limestones, which are characteristic of the Yeringian, are absent from the Jordanian.

The following Styliolina localities are regarded by the author as Yeringian:—

1. Railway cutting, south of Coldstream railway station.
2. Warburton highway, Killara.
3. West of Yankee Jim Creek.

This locality is about half a mile west of Yankee Jim Creek and 15½ miles east of Warburton on the Warburton-Wood's

Point road. Clear sections are to be seen on the road and on the aqueduct above the road. There are also outcrops on the river banks below the road. The locality represents a Yeringian outlier and possibly the centre of the synclinorium termed by Thomas the McVeigh Synclinorium (Thomas, 1939). The rocks are closely folded, with crush zones and minor faulting. There is a dyke showing on the aqueduct section. On the same section two anticlines and two synclines (*vide* text-figure 1) can be seen in 300 yards, whereas elsewhere the structure consists of broad open folds. This locality occurs between westerly dipping Jordanian beds at Yankee Jim Creek and easterly dipping

FIG. 1.—Syncline in closely-folded strata shown on aqueduct cutting west of Yankee Jim Creek, Upper Yarra District.

Jordanian beds at McMahon's Creek. This outlier gives corroborative evidence to Skeats' paper (1928), which describes the "Tanjilian" beds as underlying and not overlying the Yeringian series, as was originally suggested (Chapman, 1924). From the aqueduct and road cuttings (*in situ* and from loose rock) the following fossils have been collected:—

cf. *Hostimella* sp. Abundant.
Zosterophyllum australianum Lang and Cookson.
Styliolina fissurella (Hall). A solitary individual. The species occurs thus at Lilydale.
Spirifer of the *lilydalensis* Chapman type. Abundant.
Anoplia, sp. nov. Abundant. *Vide* Gill, 1940.
Reyrichia cf. *kloedeni* McCoy. *Reyrichia* is not known from the Jordanian but is abundant in the Yeringian.
Tubuliporinid bryozoan (cf. *Reptaria*).
Fenestella cf. *margaritifera* Chapman.
Crinoid stem joints. Common. Crinoids are not common in the Jordanian but are abundant in the Yeringian.

It has been noticed in the localities examined that in Yeringian outcrops *Styliolina* is restricted to narrow bands or occurs as isolated individuals, whereas in the Jordanian it occurs in great numbers through great thicknesses of rock.

Recently, the author (Gill, 1940) discussed the extent of the Yeringian rocks between Lilydale (type area) and Melbourne (type area of the Melbournian). Subsequent work has shown that there is a band of conglomerate north of Ringwood ($\frac{1}{4}$ mile west of where the five roads meet on the Ringwood-Warrandyte road) which has decalcified corals, bryozoa, brachiopods, and crinoids, such as are found in the Lilydale district. This conglomerate is probably the base of the Yeringian. This new locality is the southerly extension of the conglomerate mapped by Jutson (1911). It is seen on his map (plate XCII.) along the Consols and 5th Hill anticlines, which are subsidiary structures on the Warrandyte anticlinorium. In places the conglomerate gives way to a heavy sandstone or grit with inclusions of mudstone. A similar rock is found west of Yankee Jim Creek containing the Yeringian fossils already named. The *Spirifer*, *Fenestella*, crinoid fragments, and Tubuliporinid bryozoan are common to both localities.

Whether Jordanian rocks occur between the Yeringian conglomerate north of Ringwood and the Melbournian rocks further west has yet to be discovered. It should be noted that *Panenka* cf. *cingulata* Chapman has been found at One Tree Hill some miles north on the same Warrandyte anticlinorium (Chapman, 1908). Mr. R. B. Withers and the author found in a small road cutting just outside the Watson's Creek State School (north of Warrandyte) specimens of *Anoplia* (which show that the beds are probably Yeringian) and a pelecypod referable to the genus *Posidonomya*. This genus is unknown from the Yeringian strata, but it is not uncommon in the Jordanian beds between Muddy Creek and the McMahon's Creek village in the Upper Yarra District, west of the Yeringian outlier. The presence of *Anoplia* and *Posidonomya* at Watson's Creek suggests an early Yeringian age, i.e., not far removed from the Jordanian. This view is consistent with the structure of the area as at present known. That the Jordanian series represents a definite time-period and not just a facies synchronous with the Yeringian elsewhere is shown by the structure of the Walhalla synclinorium where Jordanian rocks appear between the Melbournian graptolite beds and strata with typical Yeringian fossils. The interposed Jordanian series helps to explain the great dissimilarity between the Melbournian and Yeringian faunas. Chapman (1913) writes, "In the Melbournian division, 136 fossil forms are recorded; whilst in the Yeringian there are no less than 206 species. . . . Of the Melbournian and Yeringian series, only sixteen species are in common, showing the division between the two to be well marked, and probably separated by a distinct geological pause in sedimentation." The figures now are approximately—Melbournian, 137 species (this figure is almost the same because, although new forms have been added to the fauna, some localities previously regarded as Melbournian are now classified as Yeringian),

Yeringian, 259 species, and common to both series, nineteen species. A large number of Yeringian forms awaiting description further accentuate the difference between the Melbournian and Yeringian faunas. However, the presence of *Panenka* and *Posidonomya* north of Warrandyte shows that possibly there are Jordanian rocks between the basal conglomerate described above and the Melbournian beds further west. The unfossiliferous character of the rocks makes the determination of this point most difficult. Another possibility is that the Jordanian beds thin out so as not to appear at the surface in this area, as is the case with the Mt. Useful beds on the western side of the Walhalla synclinorium (*vide* Skeats, 1928, pl. II.). The boundary between the Melbournian and Yeringian would then be a disconformity.

The following *Styliolina* localities are regarded by the author as Jordanian:

1. Between Jordan River and B.B. Creek. Type locality for the Jordanian series.
2. Erica District (Chapman, 1924).
3. Eighteen-mile Quarry (i.e., east of McVeigh's), Yarra Track.
4. East of Yankee Jim Creek.
5. McMahon's Creek (Chapman, 1904).
6. Between Muddy Creek and McMahon's Creek village.
7. Muddy Creek (west bank beside Warburton-Wood's Point road).
8. Starvation Creek.
9. Mt. Matlock.
10. ? Powlett River bore.
11. ? Howe's Creek Quarry, Loyola.

The following localities are regarded by the author as Melbournian:

1. Nineteen-mile Quarry, Yarra Track. The author has collected with *Monograptus* the following forms:—

Baragwanathia longifolia Lang and Cookson.
Yarravia oblonga Lang and Cookson.
Pterygotus sp.
Orthoceras sp.
Ceratiocaridae indet.

2. Twenty-mile Quarry, Yarra Track. At this locality the author has collected *Monograptus* and plant remains. Harris and Thomas (1937) record from here *Monograptus vomerinus* and *M. vomerinus* var. *crenulatus*.

3. Thompson River, near Machinery Spur (Skeats, 1928).

From the foregoing list of localities it may be seen that *Styliolina* ranges in Victoria from the Melbournian through the Jordanian to the Yeringian.

Systematic List of Jordanian Fossils.

The numbers following the names of the fossils are the numbers of the Jordanian localities listed above. The fossils marked with an asterisk are new recordings, and the specimens are in the writer's collection.

PLANTAE:

cf. *Hedeia corymbosa* Cookson.—3*.
cf. *Hostimella* sp.—Yankee Jim Creek*.
Zosterophyllum australianum.—3*; Yankee Jim Creek*; 10½ mile Quarry, Yarra Track*.
Indeterminate plant remains are found at numerous localities.

ANTHOZOA:

Heliolites sp.—Yankee Jim Creek*.

CRINOIDEA:

Small stem joints.—7*; Yankee Jim Creek*; 9 mile Quarry, Yarra Track*.

ANNELIDA:

Cast of tube.—10½ mile Quarry, Yarra Track*.

BRACHIOPODA:

Athyris sp.—6*, 7*.
Atrypa sp.—7*.
Chonetes sp. nov.—6*.
Cyrtina sp.—6*.
Lingula sp.
Orbiculoidea sp.—6*

PELECYPODA:

Actinopteria sp.—1.
Lunulicardium antistriatum Chapman.—5, 9, "Reefton."
Paneuka cingulata Chapman.—5.
P. gippslandica (McCoy).—1, 2, 3, 4*, 5, 8, 9.
P. planicosta Chapman.—9.
Panenka sp. nov. (?).—6*.
Paracardium filosum Chapman.—8.
? *Paracardium* sp.—1.
Posidonomya sp.—6*.
Sphenotus warburtonensis Chapman.—"Reefton."

GASTEROPODA:

cf. *Euomphalus* sp.—8 mile Quarry, Yarra Track*.
Hercynella, sp. nov.—7*.
Zygospira sp.—7*.

PTEROPODA:

Coleolus aff. *aciculum* Hall.—7*.

Hyolithes sp.—7*.

Styliolina fissurella (Hall).—1, 2, 3, 4*, 5, 6*, 7*, 8, 9*, 10, 11.

Tentaculites matlockiensis Chapman.—1, 3*, 4*, 6*, 7*, 9.

Tentaculites sp. (large).—8 mile Quarry, Yarra Track*.

CEPHALOPODA:

Kionoceras cf. *striatopunctatum* Munster.—10.

Orthoceras spp.—1, 3, 4*, 5, 6*, 7*.

PHYLLOCARIDA:

Ceratiocaris sp.—1.

Summary.

1. A critical discussion of the genus *Styliolina* is given, and the Victorian specimens determined as *S. fissurella* (Hall).

2. Data are provided concerning the faunal associations of *Styliolina*, and *Tentaculites matlockiensis* Chapman is redescribed.

3. *Styliolina fissurella* is shown to have a long geological time-range in Victoria (as it has in North America), but at an earlier period, viz., Melbournian—Jordanian—Yeringian, which is Lower Ludlow to Lower Devonian.

4. The "Tanjilian" series of Chapman is critically discussed and the Jordanian series proposed. A systematic list of Jordanian fossils is provided. A Yeringian outlier in the Upper Yarra District is recorded. A fossiliferous conglomerate which is probably the base of the Yeringian is recorded from north of Ringwood.

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Explanation of Plate.

PLATE IV.

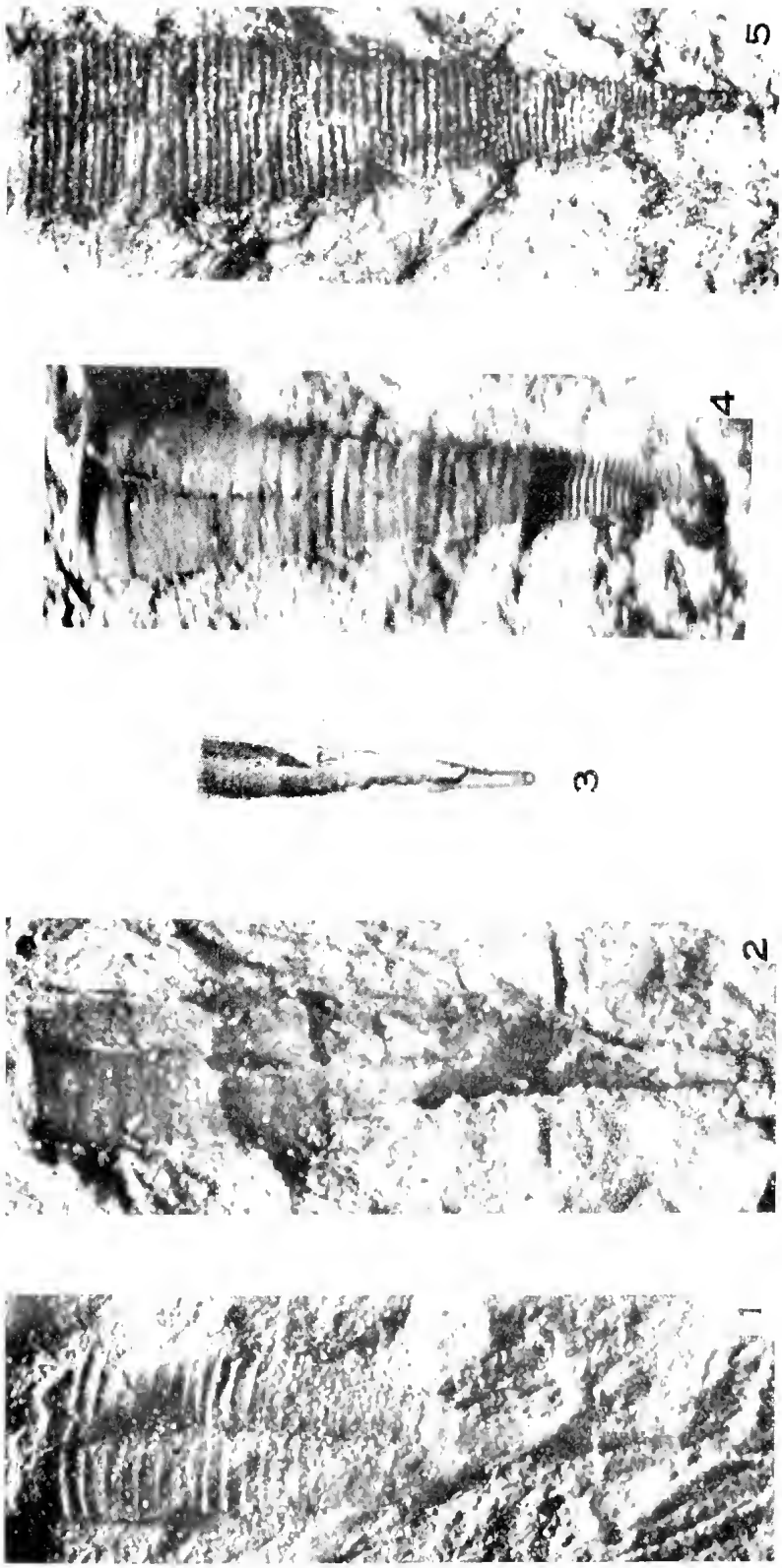
Fig. 1.—Photomicrograph of *Tentaculites matlockiensis* Chapman. Type specimen, National Museum, Melbourne.

Fig. 2.—Photomicrograph of *Styliolina fissurella* (Hall). Type specimen of Chapman's variety *multistriata*.

Fig. 3.—Photomicrograph of *S. fissurella* taken by Mr. F. Chapman. Note faint striae at stomatic end.

Fig. 4.—Photomicrograph of *Tentaculites matlockiensis*. Internal mould with external cast showing at apical end.

Fig. 5.—Photomicrograph of *T. matlockiensis* hypotype from Muddy Creek, Upper Yarra District. National Museum reg. no. 14089.



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[Proc. Roy. Soc. Victoria, 53 (N.S.), Pt. I., 1941.]

Art. IV.—The Silurian Rocks of the Studley Park District.

By EDWIN SHERBON HILLS, Ph.D., D.Sc.

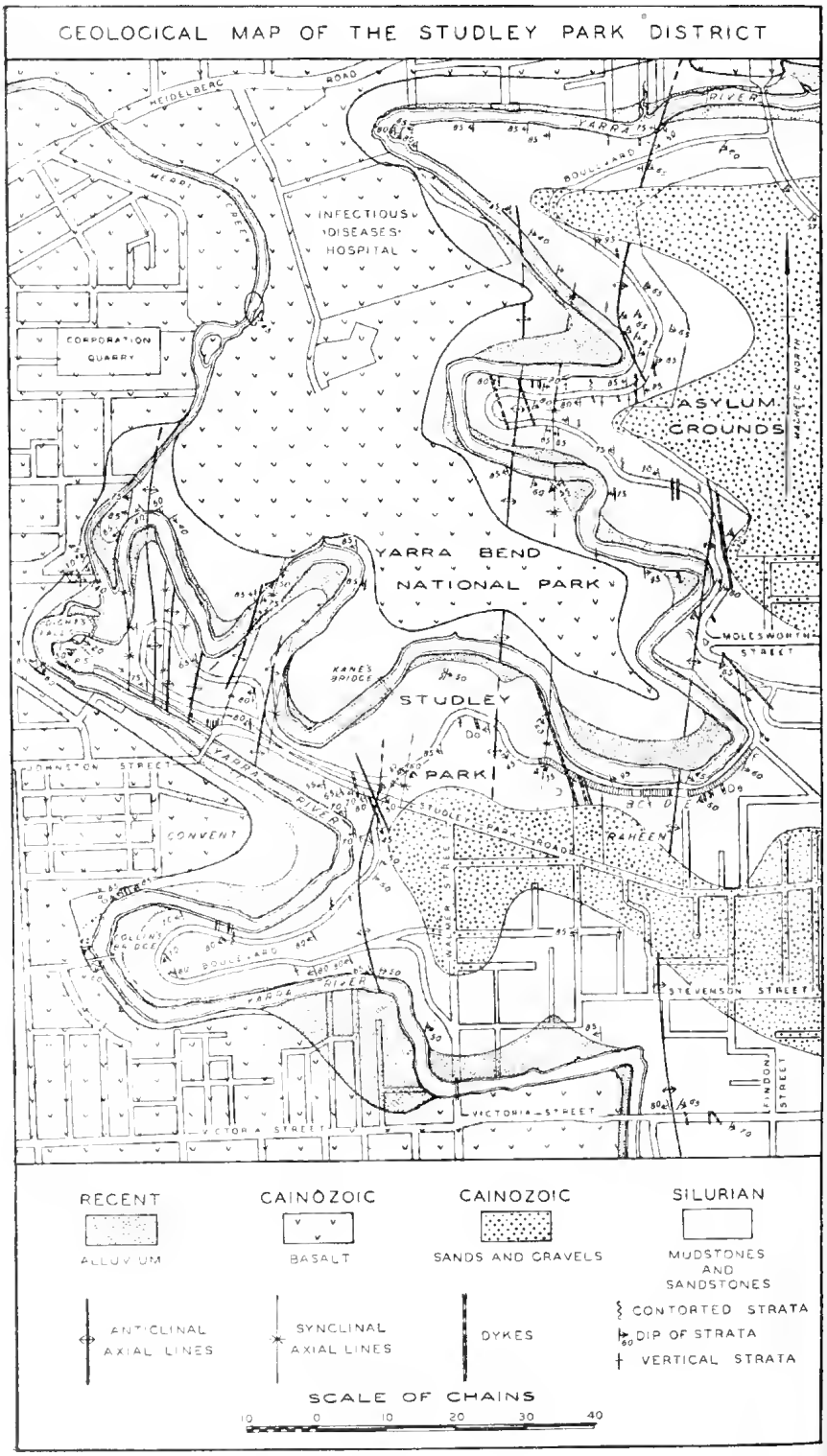
[Read 13th June, 1940; issued separately 1st February, 1941.]

Contents.

Introduction.
Palaeontology.
Folding.
Faulting.
Jointing.
Cleavage.
Dyke Intrusions.
Structural Details in the Silurian Rocks.
Origin of Major Structures.

Introduction.

The construction of the Yarra Boulevard between Studley Park and Fairfield recently afforded an excellent series of road sections, which the author took the opportunity of investigating while constructional work was in progress, in order to elucidate the complex folding, faulting, and other structural features exhibited by the Silurian strata that form the bedrock of the district. The sections available for detailed study, including the river banks and excavations for roads and tracks, amounted to upwards of 12 miles, although the Silurian rocks occupy only about one square mile in the area mapped. This area is included in quarter-sheet No. 1, N.E. (Melbourne), of the Geological Survey of Victoria, and also in Miss Nicholls' map of the axial lines of folds in the Silurian rocks in the eastern suburbs of Melbourne (Nicholls, 1930). The data available to the present author indicate that the structural information as to dips, strikes, and folds shown on both these maps is unreliable, but only minor changes have had to be made in the geological boundaries on the quarter-sheet. In spite of careful and repeated examination of every outcrop and section, however, it was found impracticable to map all the minor folds, especially in the "crush zone" between Johnston Street Bridge and Dight's Falls. In general, the chief axial lines shown on the map (fig. 1) have been located accurately in the field over considerable distances, though in a few places the delineation of major structures is still somewhat uncertain. For information concerning the general geology of the district the paper by Hauser (1923) may be consulted, the present contribution being concerned only with the Silurian rocks, and the dyke intrusions that penetrate them.


GEOLOGICAL MAP OF THE STUDLEY PARK DISTRICT
HEIDELBERG ROAD
YARRA RIVER
BOULEVARD
INFECTIOUS DISEASES HOSPITAL
CORPORATION QUARRY
ASYLUM GROUNDS
YARRA BEND NATIONAL PARK
KANE'S BRIDGE
STUDLEY PARK
STUDLEY PARK ROAD
MOLESWORTH STREET
JOHNSTON STREET
CONVENT
ALEXANDRA PARADE
STEVENSON STREET
VICTORIA STREET
RECENT
ALLUVIUM
CAINOZOIC
BASALT
CAINOZOIC
SANDS AND GRAVELS
SILURIAN
MUDSTONES AND SANDSTONES
ANTICLINAL AXIAL LINES
SYNCLINAL AXIAL LINES
DYKES
CONTORTED STRATA
DIP OF STRATA
VERTICAL STRATA
SCALE OF CHAINS
10 0 10 20 30 40

Palaeontology.

Fossils have previously been obtained from the track to the Pumping Station (*P.S.* on the map, near Dight's Falls) and also from the spur above the Falls. Hauser listed *Monograptus* sp., cf. *Streptelasma*, *Camarotoechia decemplicata*, *Chonetes melbournensis*, and *Loxonema* sp. from these localities, and Jones (1927) recorded *Monograptus chimaera*, *M. roemeri*, *M. colonus*, and *M. varians* from the track to the Pumping Station. Harris and Thomas (1937) determined *M. crinitus* from this section, and Withers and Keble (1934) described a new species of brittle-star, *Furcaster bakeri*, in a collection made by Mr. G. Baker from the loop in the Boulevard north of Johnston Street Bridge. The Rev. E. D. Gill has kindly examined Mr Baker's collection and also fragmentary shelly fossils obtained by me from the foundations of a pylon north-west of Victoria Bridge, from the northerly extension of these beds on Studley Park Road, and from sewerage excavations in Kevin Street; he has supplied the following list of forms so far identified from the Studley Park district:

PLANTAE:	*Bythotrephis divaricata* Kidston, *B. tenuis* Hall.
COELENTERATA:	cf. *Streptelasma*, *Monograptus chimaera* (Barrande), *M. colonus* (Barrande), *M. roemeri* (Barrande), *M. varians* Wood, *M. crinitus* Wood
ANNELIDA:	*Keilorites* sp.
ARACHNIDA:	*Hemiaspis tunnecliffei* Chapman.
MOLLUSCA:	*Pleurotomaria* sp., *Loxonema* sp., *Hyolithes* sp.
BRACHIOPODA:	*Chonetes melbournensis* Chapman, *Nucleospira australis* McCoy, *Plagiorhyncha decemplicata* (Sowerby), *Rhynchatrema liopleura* McCoy, *Spirifer* sp. nov. (?).
ECHINODERMATA:	*Furcaster bakeri* Withers and Keble, *Sturtzura brisingoides* (Gregory), Crinoid stem joints.

In spite of careful searching along the excellent sections north of the tunnel beneath Studley Park road, no fossils have been obtained in this part of the area, and the palaeontological data now available necessitate no change either in the earlier reference of the strata to the Melbournian Series, or their correlation with the *M. nilssoni* Zone of the Ludlovian of Great Britain (see Jones, 1927; Chapman and Thomas, 1935).

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Folding.

Miss Nicholls (1930) indicated a synclinal axial line immediately to the east of Dight's Falls, the "Studley Park" anticline just over half a mile further east and extending across the whole of the area dealt with in this paper, and a syncline at the bend in the Yarra River east of "Raheen." As may be seen by inspection of figure 1 and Miss Nicholls' map, the generalizations made by her in extrapolating axial lines from a few observed field apices have not been borne out by more detailed work on the excellent exposures that were available to the present author. The axial lines shown by Miss Nicholls trend N. 25° W., whereas actually the trend ranges between N. 15° W. and N. 5° W. in the north of the area, to N. 10° E. in the south. Thus the Victoria Bridge anticline, which as previously represented appeared to deviate notably from the general trend, is actually one of the major folds of the district, and fits into the tectonic framework in a normal manner (cf. Nicholls, 1930, p. 132).

The zone of closely packed minor folds near Johnston Street Bridge is sharply delimited on the east, terminating near the entrance to the Boulevard from Studley Park Road. The southerly continuation of this zone is found north of Collins' Bridge, but it is obscured further south, and also in the north, by late Cainozoic basalt flows. The formation of these complex minor folds is undoubtedly connected with the presence of massive sandstones at Dight's Falls, as was recognized by Miss Nicholls. Most of these minor folds are approximately congruous drag folds (see Hills, 1940, p. 90) ranging in strike from 360° to 22°, and pitching south at angles up to 15°. In the river cliff opposite Deep Rock Pool, the strongly disharmonic nature of the minor folding in this section is evident. Miss Nicholls has given two alternative sections to illustrate the structure near Dight's Falls, both based on the assumption that the sandstones at the Falls are not represented in the section along the track to the Pumping Station. These interpretations are, however, open to doubt because of a misreading of the dip at the Falls, which is south-easterly, and not north-easterly as recorded by her. The present author agrees that the structure is in general synclinal, but concludes that the sandstones at the Falls are represented in the west-dipping limb at the western end of the track to the Pumping Station, and that, as is usual in the district, the pitch is to the south, and not to the north, as was suggested (cf. Nicholls, 1930, pp. 131-2).

The folds are of the zig-zag type, asymmetrical, listing towards the east in depth, with vertical or slightly overturned strata in many of the west-dipping limbs, and dips of about 60°–65° commonly occurring in the east-dipping limbs. Throughout the area the pitch is southerly, although in the north many observed fold apices are horizontal. The southerly pitches themselves show

a remarkable range. Thus the Victoria Bridge anticline, on the River north of "Raheen," pitches at 30°, the syncline east of the tunnel under Studley Park Road pitches at 50°, and a drag fold in the river cliff south of the Convent pitches at 90°, the adjacent strata themselves dipping at this angle (fig. 2).

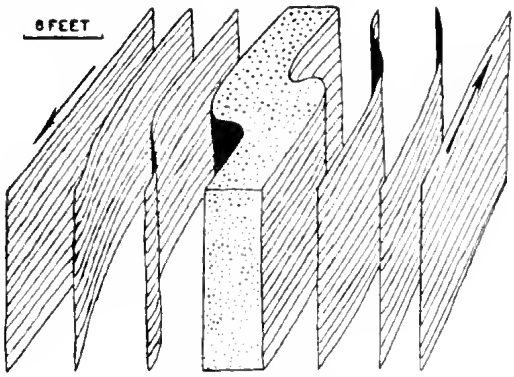

FIG. 2.—Incongruous drag fold pitching at 90° River cliff north of Convent.

Numerous other examples of small drag-folds pitching at high angles occur in the district, where, as is also shown by slickensides, considerable bedding-plane slip in directions ranging from parallelism with the dip to parallelism with the strike of the folded strata has gone on. The apices of the resultant drag-folds pitch in a southerly sense at angles ranging from 0° to 90°. Drag-folds caused by horizontal shearing movements in already highly inclined strata have been termed "independent" by Derry (1939),

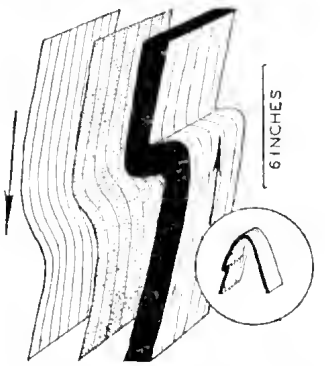

FIG. 3. Incongruous drag fold, E. end of Victoria Bridge Cutting. Inset in circle shows diagrammatically the relation of the drag fold to the Victoria Bridge Anticline.

signifying that their development resulted from forces independent of those causing the main folding. If, however, there was a horizontal shearing couple involved in the folding, even locally (see Hills, 1940, p. 58), horizontal bedding-plane slip

would in all probability take place after the beds were folded, leading to the development of the so-called "independent" drag folds. The present author therefore prefers to term such drag-folds "incongruous," signifying that they do not agree with Pumpelly's Rule, but not implying that they are necessarily of a distinct and separate origin from the major folding.

Near the eastern end of the Victoria Bridge cutting, on the south side, there is a small drag-fold (fig. 3) that is incongruous in yet another sense, for, as shown in the inset in figure 3, it apparently indicates movement of the upper strata away from the anticlinal axis, and not towards it as is usual. This arrangement is the same as was observed by Bain (1931) in the limbs of anticlines in limestone, the drag-folds ("flowage folds") being caused by the slipping of strata down the anticlinal limbs, away from the fold axis. The same explanation may hold for the present example.

Faulting.

As has been remarked by Hauser (1923) and Miss Nicholls (1930) reverse faults are common in the Studley Park district, but the surprisingly large number of such faults present has only been revealed by the new sections, in which a considerable number of normal faults is also shown. The dip and strike of 100 faults could actually be measured, and frequency diagrams representing the direction of dip of these faults have been prepared (fig. 4). There are, however, innumerable faults with a

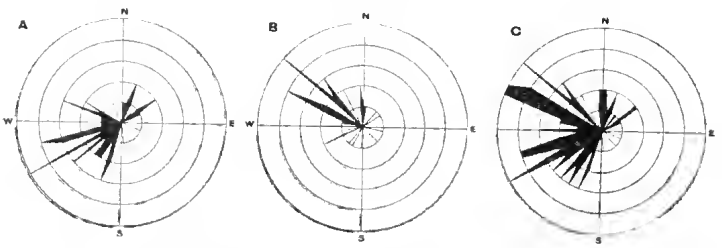

FIG. 4.—Frequency diagrams of direction of dip of 100 fault planes along the Yarra Boulevard. *A*, southern area—between *A* on profile *AB*, and Molesworth St.; *B*, northern area—north of Molesworth St.; *C*, composite diagram of all faults. Interval for bearings, 5 degrees; circles unit distance apart—one fault per circle.

slip of the order of an inch, that were not measured, and many others with greater amounts of slip, whose strike and dip could not be determined. The fact that westerly-dipping fault planes are by far the commonest is clearly brought out by the frequency diagrams, and is indeed obvious in the field (see profiles, figs. 5 and 6). The average angle of dip of the fault planes is 50°, and, over the whole area, the average strike is 170°.

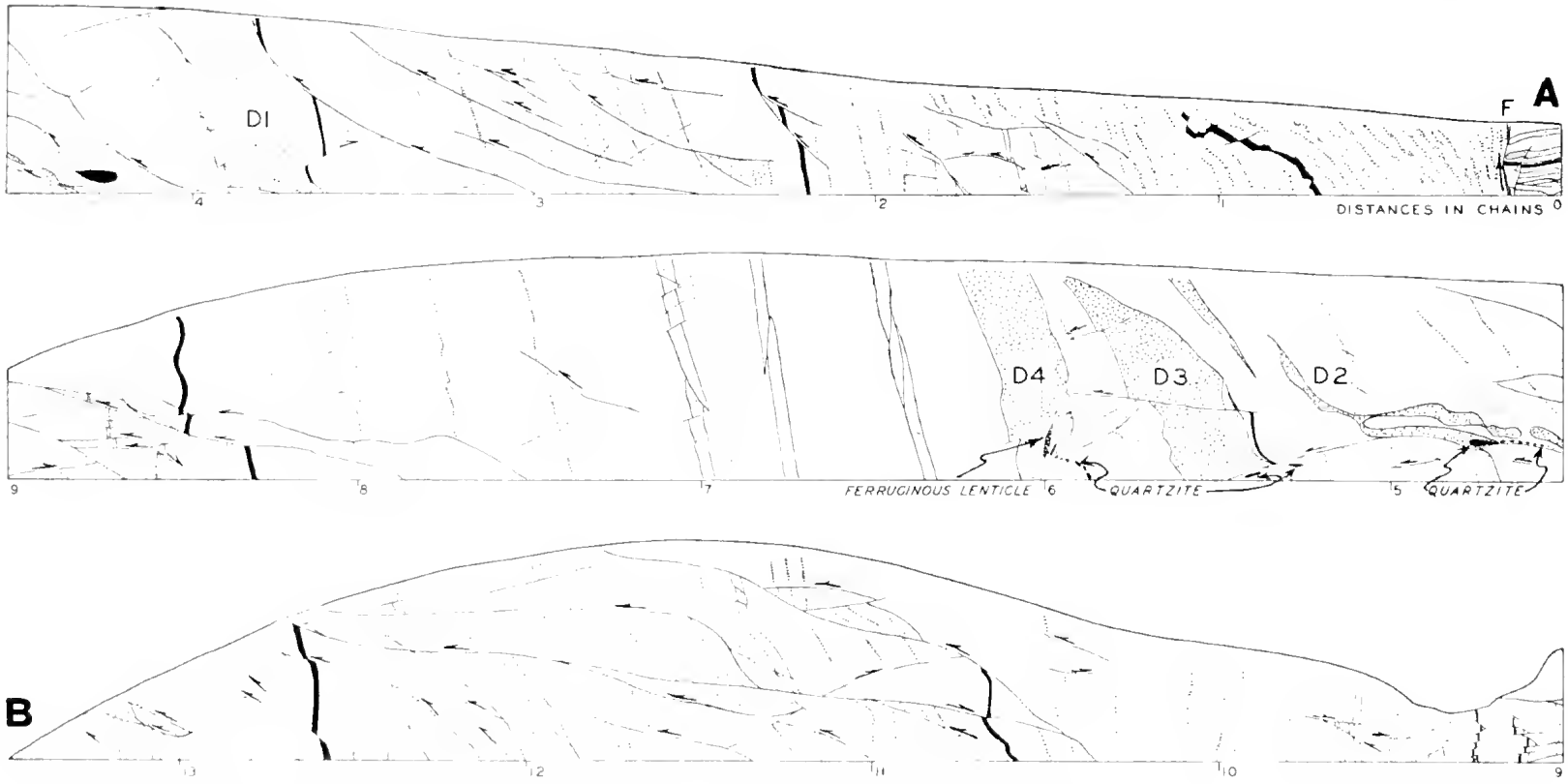

FIG. 8. Profile along the Yarra Boulevard location shown on map (fig. 1) by cross-lining of Boulevard between *A* and *B*. Key strata shown somewhat diagrammatically by conventional symbols, e.g., solid black, dots, or dots between lines. Direction or relative movement along faults shown by arrows. *F*, fault shown in detail in fig. 7. D1-4, dykes.

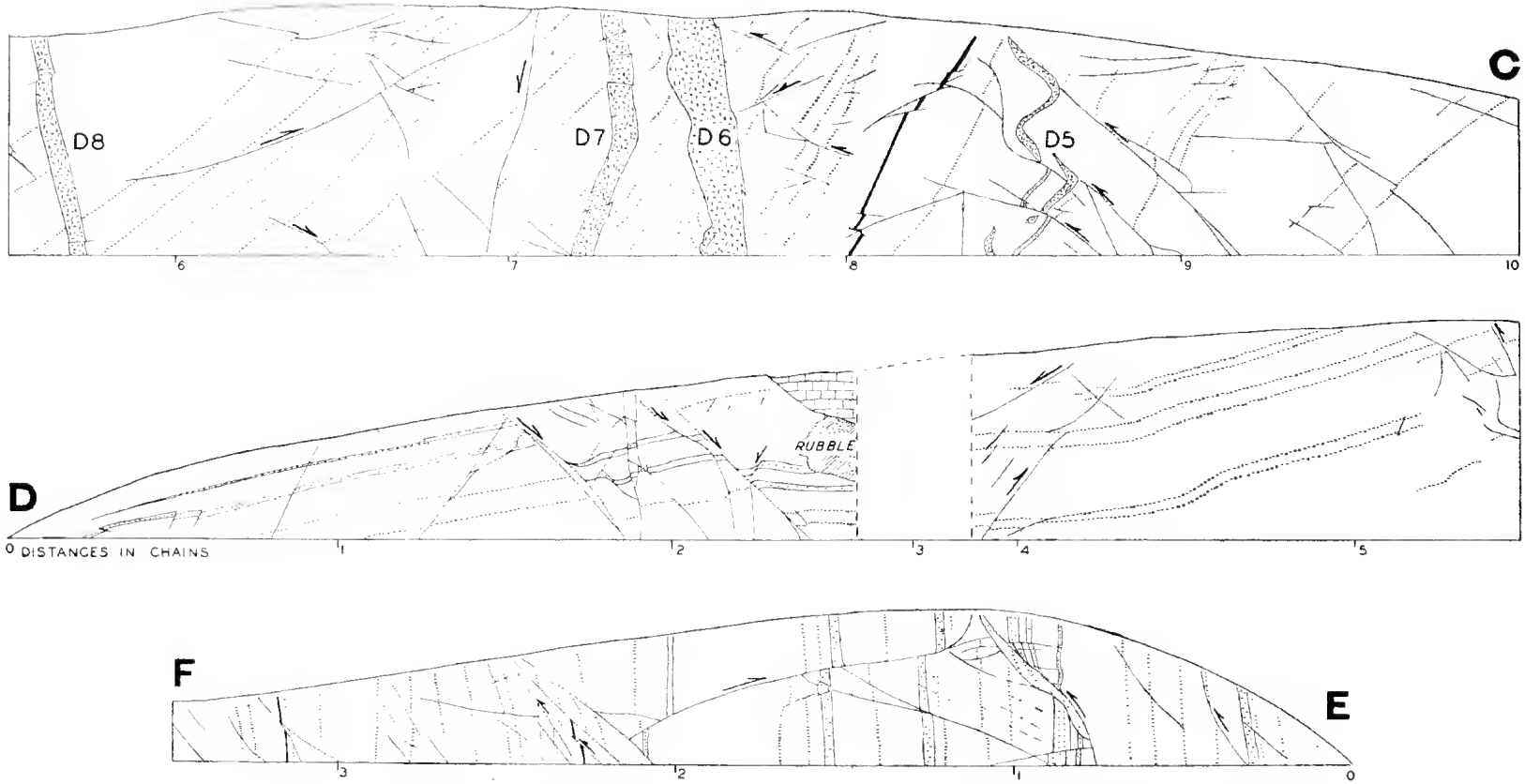

Fig. 6.—Profiles along the Yarra Boulevard: location indicated on map by cross-lining between *CD* and *EF*.

Normal Faults.

The fault labelled F in figure 5 near A, brings sheared incompetent mudstones and thin sandstones against more massive sandstones on the west. The latter show apparent "drag" both upwards and downwards, so that the direction of relative movement of the blocks is not immediately obvious. The displacement is, however, clearly indicated by the pinnate shearing planes (S, fig. 7) in the incompetent beds adjacent to the fault plane.

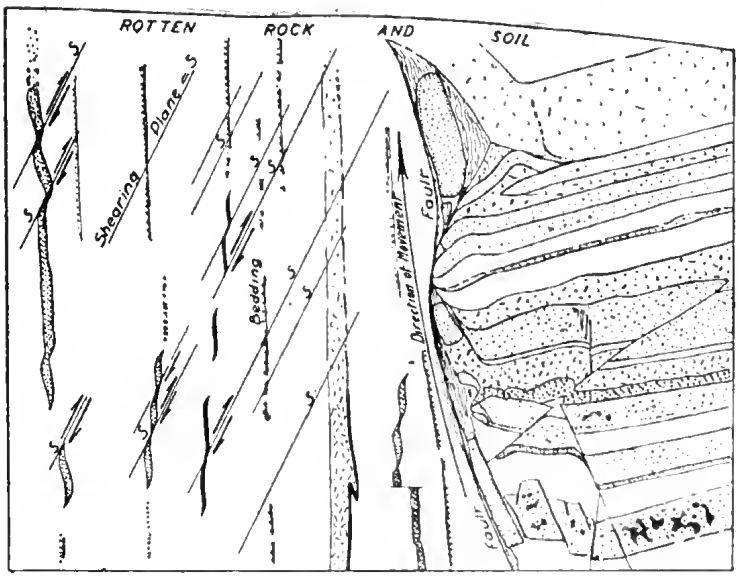

Fig. 7.—Sketch showing the structural features adjacent to fault *F* (fig. 5). The direction of movement along the fault is indicated by the downward opening of the acute angle between the fault plane and the shearing planes *S*. Length of section, 18 feet. West on right.

By analogy with the experiments of Riedel (1929) it is clear that the relative movement of the eastern block was upwards, the western downwards, this being indicated by the attitude of the pinnate shearing planes in relation to the fault plane. If the fault actually hades towards the west in depth, as it does in the section exposed, then it is a normal fault. Other normal faults occur near the 2 chain mark on profile CD (fig. 6).

Reverse Faults.

The great majority of the faults in the district are reverse, being shear thrusts (Hills, 1940, p. 116) that have been formed in already folded strata (see profiles, figs. 5 and 6). The commencement and termination of some of these faults may be seen in the sections, the general arrangement being as shown in figure 8. In almost every case, the strata at the end of a shear thrust are flexed, then the flexure is broken through, and the amount of slip increases progressively along the fault, until it reaches

a maximum, after which the slip decreases until the strata again are merely flexed and not faulted. Where there is actual separation of the strata, the so-called "drag," which may be used to

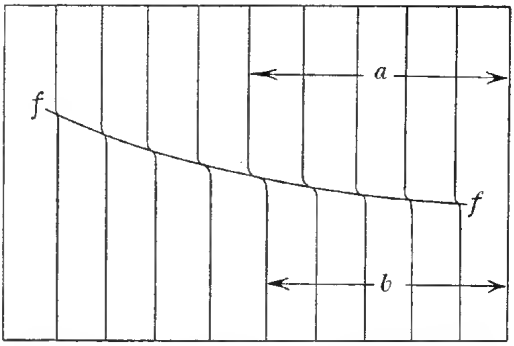

FIG. 8.—Diagram showing the mode of development of shear thrusts at Studley Park. Note the preliminary shear flexing at the ends of the fault plane *f f*, and the increasing slip towards the centre of the fault. Measured examples show *a* : *b* as 20 : 19.

determine the direction of relative displacement of the fault blocks, is seen to be the result of the shearing through of the preliminary flexure, and not due to friction along the fault plane. In many instances, the flexing alone is developed, along a plane that would, if more displacement had occurred, have become a fault. It is proposed to designate such structures as "shear flexures." In massive strata, the "drag" effect results from a small amount of preliminary shear flexing, combined with numerous small displacements along subsidiary fracture planes (see top of profile EF above the 1 chain mark; also Pl. V., fig. 1).

High-angle reverse faults, many of which are closely connected with individual folds, are common in the "crush zone" near Dight's Falls. (See fig. 10A; also Section B in Nicholls, 1930, p. 134.)

BEDDING FAULTS.

In all sections, there is evidence of marked slipping of strata along bedding planes. The existence of definite bedding faults, as distinct from bedding-plane slip consequent upon the folding mechanisms, and from pre-tectonic sliding movements which will be discussed below, is indicated by the passage of thrust-fault planes into bedding planes in many localities.

Jointing.

Complex jointing is present throughout the area, and it is not always possible to decide upon the origin of particular joints observed in the field. It is clear, however, that the majority of

the joints, especially those that may be seen to traverse several adjacent beds, are shear joints, cognate with the reverse and normal faults. This is shown by the parallelism of joint and fault planes, and the complete gradation observable between faults and joints, as regards the amount of slip (see Pl. V., fig. 2). Many fault planes indeed commence as shear joints, and in other instances parallel shearing planes include examples of both faults and shear joints, the slip along the latter not being of sufficient magnitude to enable it to be determined. In profile CD, between the 1 and 2 chain marks, a clear example showing two intersecting sets of shear joints, each set parallel to a fault plane, suggests that other examples of intersecting joint sets, which are especially characteristic of the sandstone strata in the Melbourne district, have a similar origin as incipient complementary shearing planes of tectonic origin. It is probable, however, that many of the joints in both sandstones and mudstones are not of tectonic origin, but were produced by weathering. Thus in several instances successive sandstone beds are independently jointed, each bed exhibiting intersecting joint sets, normal to the bedding planes, and enclosing a different dihedral angle in each stratum. The arrangement, which is shown diagrammatically in figure 9, and

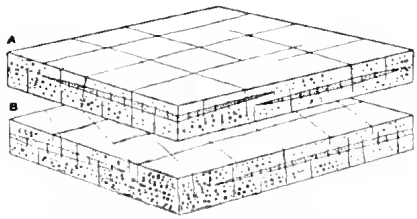

FIG. 9. Diagram showing the nature of intersecting joints sets in adjacent sandstone strata, probably due to weathering. *A* and *B*, laminated sandstones with interbedded lenticles of structureless sandstone. In *A* joints intersect at 60°; in *B* at 90°.

the fact that on close study the joint planes appear to be open gashes, suggest that the joints in the sandstones are caused by expansion of interbedded mudstones in the zone of weathering, due both to mineralogical changes and to swelling of the clay fraction on wetting. Such expansion would have been transmitted to the sandstones owing to the adherence of the strata with one another, and it is suggested that the joints in the sandstones developed as a result. Expansion of the sandstones themselves would also have contributed to the process, and removal of the load of superincumbent rock by erosion may also have played a part in the development of jointing in the superficial rocks.

Cleavage.

Regional cleavage is not developed in the area, in spite of the close folding to which the rocks have been subjected. At three localities, however, there is a local development. In the anticline along the track to the Pumping Station (3 chains from the commencement of the section near the bridge—see fig. 10) a

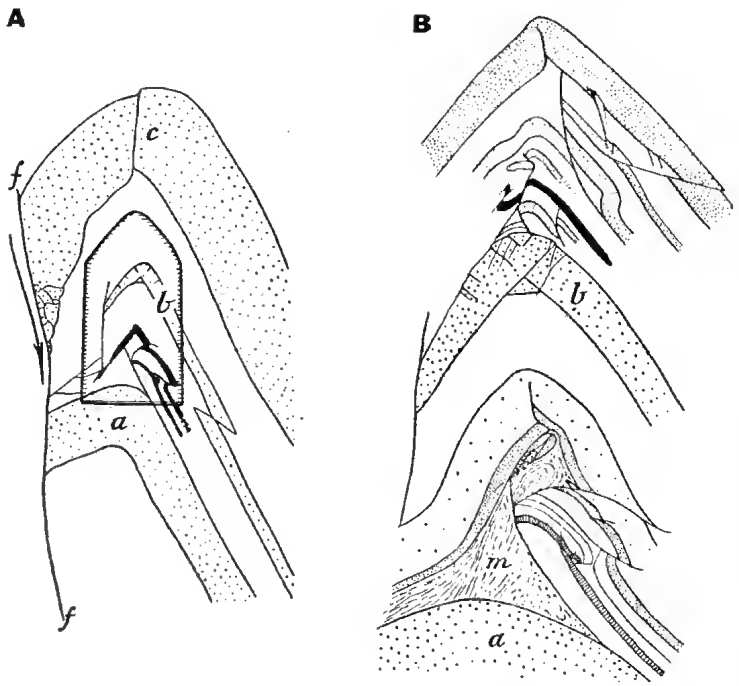

Fig. 10.—*A*. Anticline at 3 chains from the commencement of the section near the Bridge, on the track to Pumping Station. Height of section, 8 feet. The shaded area between the massive sandstones *a* and *c* is represented in detail in Fig. 10*B*. See also photograph in Nicholls, 1930, Pl. X., Fig. 1, *f f*, fault.

B. Detail between beds *a* and *c* in *A*. Height of section, 3 feet. Note the evidence of flow in mudstones *m*, fracturing of sandstone *b* at the fold apex, and minor shearing and flexing of sandstone layers interbedded in mudstones, the displacements indicating flowage towards the fold apex, parallel to the major bedding planes.

patch of mudstone squeezed along the fold limb near the apex shows a definite cleavage over an area of a few square inches. The cleavage planes are curved, as with typical fracture cleavage in such an environment, and under the microscope they are seen to be rather indistinct shearing surfaces, associated with the minute shear flexures typical of slip-strain cleavage. Cleavage is also present in mudstones in an exposure of a few square yards in the outfall of the Riley Street drain, where there is intense brecciation of sandstones and flowage of mudstones in a zone

of shearing. The most extensive occurrence of cleavage is, however, adjacent to dyke D8 (see profile CD, fig. 6). There, sandstones and mudstones are both cleaved, though the cleavage is better developed in the mudstones. It is parallel to the dyke walls, following irregularities in them, and is well developed for a distance of 5 yards from the dyke on the western side, becoming indistinguishable at 10 yards. On the east cleavage is developed for only one yard from the contact. The strata have been metamorphosed for a distance of about one yard along each wall of the dyke, three zones being distinguishable. Adjacent to the dyke the strata have been rendered soft for about 6 inches. Then there is a zone about one foot to two feet wide in which both sandstones and mudstones have been hardened, and finally the outer zone, up to two feet wide, has been leached to a pale cream colour.

The persistence of the cleavage into the hardened zone indicates that the formation of cleavage antedated the metamorphism of the strata, but there can be no doubt that the cleavage bears some relationship to the presence of the dyke. The latter is unusual in that it contains numerous cognate and foreign xenoliths. Its western face is polished and slickensided, while its eastern is crumbly and shows no evidence of movement. The western face also shows undulations and steps, indicating that it is a fault plane, along which the adjacent country rock on the west has been displaced (relatively) downwards. Under the microscope the cleavage planes in the hardened rock of the zone of metamorphism show no evidence of shear, and their nature could not be satisfactorily elucidated. Finally, it may be noted that mudstone beds are shattered in the hardened zone, though showing regular cleavage without marked shattering further from the dyke, and that near the bottom of the dyke in the road section the metamorphic zones show a clear displacement of about a foot, along a bedding fault.

The interpretation of these data is as follows:—

1. There has been post-solidification faulting along the western contact wall of the dyke.

2. Minor post-metamorphic faulting has taken place along planes intersecting the dyke.

3. The cleavage antedated the final stages of the metamorphic processes.

4. The parallelism of the cleavage with irregularities in the dyke walls, the presence of only one set of cleavage planes, which traverse sandstones and mudstones alike, and the absence of shear flexures on cleavage planes, indicate that the cleavage is not tectonic in origin.

Since it is extremely improbable that such a local cleavage zone should have been developed except in relation to the dyke intrusion, while on the other hand such cleavage zones are absent from all the other dykes in the district, the conclusion is reached that the cleavage resulted from volume changes in the country rock as a result of the permeation through it of solutions of magmatic origin. The possibility that the cleavage resulted from the compression of the strata as a result of the forcible injection of the dyke cannot, however, be rigidly excluded.

Ultimately, the magmatic solutions caused the metamorphism that is now preserved, but the final production of the metamorphic zones post-dated the development of cleavage. It will now be clear that the cleavage along this dyke has no bearing on the question as to whether or not regional compressive forces operated after the dyke intrusions.

Dyke Intrusions.

Numerous narrow dykes, ranging from a foot or even less to about 10 feet wide, traverse the Silurian rocks (Pl. V., figs. 3 and 4). In no place do they intersect the overlying Cainozoic sands and gravels, but nevertheless their age has been regarded as Tertiary, because a fresh dyke at South Yarra proved to be a lamprophyre, and the lamprophyric dykes of the Midlands goldfields are usually regarded as Tertiary (Edwards, 1934). It is not proposed to discuss herein the general question of the age of the dyke and other minor intrusions throughout the Melbourne district or farther afield, but it may be noted that in addition to lamprophyric types (one of which occurs at the corner of Church-street and Alexandra-avenue) there are acid dykes and minor granitoid intrusions in the South Yarra district. These acid rocks are almost certainly of epi-Devonian or Carboniferous age, and there are, therefore, no *a priori* grounds for assuming that all or any of the dykes at Studley Park are Cainozoic.

Most of the dykes are too thoroughly decomposed to permit their original petrological nature to be determined. Some are now plastic clays, white or cream in colour, others are of a very "short" powdery texture, with a residue of fine gritty particles. The dyke labelled Do on the map (west of "Raheen") is, however, fresh enough for study. In hand specimen the rock is seen to consist of phenocrysts of simply twinned white felspar up to $\frac{1}{4}$ in. across and $\frac{1}{2}$ in. long, together with small biotite flakes up to $\frac{1}{8}$ in. across (but generally less), set in a mottled ground mass that has a lustrous appearance owing to the presence of numerous small felspar laths. Under the microscope (see fig. 11A) the phenocrysts are seen to be anorthoclase, often in characteristic aggregates resembling glomero-porphyritic texture. A phenocryst of oligoclase, showing very narrow albite twinning lamellae, and rimmed with anorthoclase, occurs in one section

A few red-brown biotite plates are present, and also small pseudomorphs of a chloritic or serpentinous nature, obviously after pyroxene. The crystal habit of these pseudomorphs and the measurement of apparent interfacial angles suggest that the original pyroxene may perhaps have been aegirine. The ground mass is trachytic, with close-packed laths of fresh sanidine, numerous specks of weathered iron ores, and an interstitial green chloritic or serpentinous base. This rock is an anorthoclase trachyte, resembling extremely closely the anorthoclase trachytes of the Macedon district. Actually, the closest resemblance, mineralogically and texturally, is with the so-called "solvsbergites" of that district, which, in a strict petrological sense, are anorthoclase trachytes.

The nature of the more decomposed dykes at Studley Park could not be made out so clearly, but in D2 there are some felspar laths, a few biotite flakes, and numerous limonite pseudomorphs after a ferro-magnesian mineral. D3 is similar to D2, but contains also clots of cream amorphous material. The limonite-rich lenticle in D4 (see profile AB, fig. 5) contains phenocrysts of sanidine or soda-sanidine, and there are also traces of sanidine laths in the groundmass, as well as of small altered phenocrysts of a ferro-magnesian mineral. The dyke D8, adjacent to which cleavage is developed, is itself completely decomposed, but it contains numerous xenoliths. Two different types of xenoliths, one a pure white felspathic type, another resembling a graphic granite in hand specimen, were fresh enough to be sectioned.

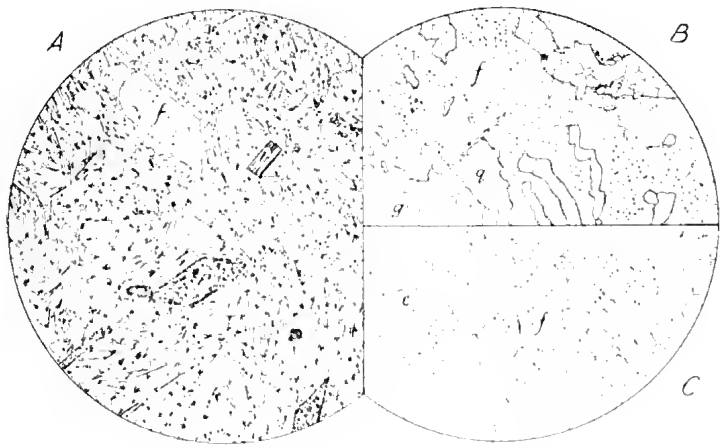

FIG. 11.—*A*. "Solvsbergite" (anorthoclase trachyte) dyke, *D9* (see Map), *f*, anorthoclase; *b*, biotite; *p*, pseudomorph after pyroxene.

B. Graphic soda-granite xenolith in dyke D8. *f*, soda-orthoclase; *q*, quartz; *g*, granular zone along shearing plane. Close stippling indicates fine-grained felspathic material, possibly injected into the graphic soda-granite.

C. Felspathic xenolith in dyke *D8*. *f*, sub-rectangular anorthoclase crystals; *c*, "clot" containing sanidine laths. All × 8.

The felspathic type (fig. 11c) is a snow-white saccharoidal rock, consisting entirely of a mass of anorthoclase crystals with an aplitic texture. It is related to the lestiwarites of Norway and Finland, which are aplites of the alkali syenite series (Johannsen, 1937, Vol. III., pp. 25-6). Rounded clots of finer grained material, containing minute alkali-felspar laths, are also present.

The other xenolith (fig. 11B) consists of an intergrowth of quartz and alkali felspar, the latter probably a cryptoperthitic soda-orthoclase. Originally the intergrowth appears to have been graphic, but granulation and recrystallization have affected both quartz and felspar, the former showing embayment.

It will be clear from the above descriptions that an alkaline suite of rocks is represented among the dykes, and the general similarity with the Cainozoic trachytes and "solvsbergites" of the Macedon district is obvious. The petrological evidence therefore strongly suggests that the Studley Park dykes are also Cainozoic. In view of this, it is important to investigate the relationship between the dykes and the faults, especially the reverse faults, in the district. As may be seen by inspection of profiles AB and CD (figs. 5 and 6), dykes D1, D3, and D8 have apparently been displaced by later faults. Dyke D5 is, however, clearly post-faulting, as it follows the bedding and the fault planes alternately (Plate V., fig. 3). The question arises as to whether the apparent displacements of the other faults may perhaps be due to the dykes pushing apart already faulted strata. Owing to the advanced state of decomposition of the dykes, and the absence of metamorphic effects along them (except for D8) it is not possible to investigate displacements of chilled borders or metamorphic aureoles, which would yield definite evidence with regard to the relative age of the faults and dykes. Where dykes have apparently been faulted (e.g., D1, D3, and D4), it is perhaps significant that certain of the faults appear to die away within the dykes. If the dykes were unaltered when faulted, this would not be expected, owing to the incompressible nature of the fresh igneous rock. The definite evidence that is available (for D5 and D8) indicates that faulting occurred both before and after the dyke intrusions, the only certain post-dyke displacement being, however, of small amount.

In the ferruginous sands and gravels exposed in the new pit south-east of the tunnel under Studley Park-road, there are angular pebbles of clay, closely resembling that of the decomposed dykes. As remarked above, the latter do not cut the sands, whose age is certainly Cainozoic, but of what period is uncertain. They must, however, have ante-dated the Newer Volcanic lavas of the Yarra Valley by a considerable period of time, and are usually regarded as Lower Pliocene. The dykes are themselves considerably older than these sands and gravels, and almost certainly are pre-Pliocene.

Structural Details in the Silurian Rocks.

Primary Structures.

The lithological types represented in the district include massive resistant sandstones, softer current-bedded sandstones showing "drift-bedding" according to Sorby's nomenclature (1908) or the "complete curve of current bedding" according to Bailey (1930), together with sandy and fine-grained mudstones. Usually there is a rapid alternation of thin sandy and muddy beds, but in places mudstones are subordinate, as near Dight's Falls, while elsewhere sandstones are locally subordinate.

Many of the massive sandstone strata exhibit an indistinct graded bedding, and the tops of current-bedded sandstones typically show ripple or current-mark. Typical current ripples with parallel crests are rare, but dimpled bedding planes, exhibiting "small hollows and protuberances of a few inches in diameter (cf. Jukes, 1872) are very common. This structure has been termed "current mark" by Kindle (1917), and is said to be due to irregularities in the sand-laden water-currents, or to the impinging of strong currents along sand bars or at other localities. The primary nature of this structure in the Silurian rocks of the Melbourne district, of which there has been some doubt in the past in the minds of Victorian geologists, is clearly indicated by the parallelism of the dimples and swellings in the bedding planes with current-bedding curves within the beds. No examples of oscillation-ripple mark have been observed.

Secondary Structures.

The development of a wrinkled, lobate, or mamillary base to sandstone strata, where these rest upon mudstone layers, is common in the crush zone near Dight's Falls. The structure is best shown where the incompetent beds are thin, and are interbedded as partings betwen the sandstones.

The deformation of the standstones is usually restricted to two or three inches at most at the base of each bed affected, and involves the underlying mudstones. Both sandstones and mudstones, it is clear, were capable of yielding to the deforming forces by flowage, for the wrinkles and lobes on the sandstone bases have smooth surfaces, and bedding planes in them are curved to accommodate themselves to the impressed geometrical forms. The latter, which range from elongated asymmetrical fold-like wrinkles a quarter of an inch or so apart, through rounded linguoid forms, to mammillate knobs, in places show evidence of having been affected by sliding movements between the strata, in the case of the wrinkles and linguoid forms. The mammillate forms, however, and those illustrated in figure 12A, show no clear evidence of movement.

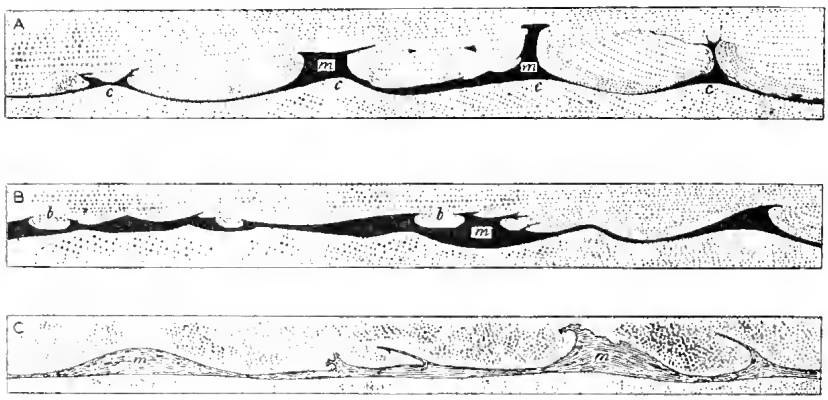

FIG. 12.—Types of mud-tone injections into sandstone strata. Mudstone shown by solid black or broken lines, sandstones stippled. *A*, mudstone injections *m* above ripple-crests *c* without evidence of differential bedding plane-slip; *B*, balling up of sandstones at *b*, *b*, and development of wave-like mudstone injections with evidence of slight bedding plane-slip. *C*, mudstone injections above a flat sandstone surface, with evidence of bedding plane-slip. All examples approximately one-third natural size. Dip vertical in the field. Location 10 yards west of *Bythotrephis* bed, Studley Park Road, near Johnston Street Bridge.

The significant data bearing on the origin of these basal sandstone deformations are as follows:—

(1) The structures are developed, so far as was observed, only where sandstones are predominant, e.g., in the crush zone between Dight's Falls and the entrance to the Boulevard.

(2) Not every sandstone stratum exhibits the structures.

(3) The deformation is shown by certain sandy beds that are only 3 inches thick, which are overlain and underlain by mudstones. In these as in all other examples, the top of the affected sandstone stratum remains undisturbed. The structure is, therefore, not due to sub-aqueous gliding, since this would have thrown the strata as a whole into folds, or developed other large or small scale mass deformations.

(4) Where linguoid or wrinkled surfaces are developed, the direction of movement indicated is not constant from bed to bed, and bears no apparent relationship to the major structures.

(5) Nevertheless, close examination of laminated sandstones and of saccharoidal sandstones showing closely spaced stratification planes shows that there has been a very general tendency for the stratification planes to develop minute asymmetrical waves in which the direction of relative motion indicated by the asymmetry of the waves agrees with the rule for folding—the upper bed moves towards the crest of the adjacent anticline.

The interpretation placed upon these facts is as follows:—

(1) For mudstone injections with no indication of differential bedding-plane slip (Type shown in fig. 12A).

In this type, injections of mudstone into the overlying sandstone are restricted to the crests of ripple-marks in the underlying sandstone stratum. Clearly, mudstone from the ripple-troughs flowed towards the crests, where it was forced into the base of the overlying sandstone. This must have occurred when the rocks were subjected to considerable pressure, and not immediately after the deposition of the basal laminae of the upper sandstone, for if the mud was sufficiently tenacious to remain in place during the deposition of this overlying current-bedded sandstone, its viscosity would not have permitted it to rise under the weight of only an inch or two of sandstone above it. Nevertheless, the, sandstone possessed sufficient fluid-plasticity to yield as shown in the diagram. It is suggested that the water expressed from the mudstone during gravitational compaction migrated into the base of the overlying sandstone, while the grains were as yet uncemented, so enabling fluid flow to take place in the lower layers of the sandstone. The mudstone injections were localized at ripple crests owing to the development of components of the vertical compressional forces on the sides of the ripples. In the troughs, the mudstone was subjected to the full compressive force, and it therefore migrated towards the points of least compression, where it was injected into the sandstones in a manner strikingly resembling the experimental salt domes produced by Nettleton (1934). As a result, the basal stratification planes of the sandstones were dragged up along the mudstone injections, producing a mammillate or linguoid surface between the injections.

Further indications that the strata were approximately horizontal at the time of development of the structure are given by the fact that the injections above the ripple-crests are normal to the bedding planes, and that all the injection phenomena are restricted to the lower surfaces of sandstones, even in vertically dipping strata. Had the strata been vertical when the structures developed, the expressed water could have entered the sandstones on both sides of the interbedded mudstones with equal ease, and the mudstone injections would have shown either a definite relationship to tectonic structures, or have risen under isostatic forces, showing a tendency to assume a vertical attitude. It is suggested that an essentially similar process, involving the expression of water from sandstones, its injection into the bases of sandstones causing them to attain fluidal properties, and the injection of sandstone into this fluid sandy mass under the gravitational force due to the load of superincumbent sediments, was involved in the formation of all the mammillate structures that show no evidence of movement.

(2) For mudstone injections into lingoid or wrinkled sandstone bases, indicating movement along bedding planes; also waved stratification planes in laminated sandstones.

Movements along the bedding planes may be either pre-tectonic or tectonic in origin. The former, it is suggested, may be developed as a result of the differential compaction of sands and muds, especially when the strata are markedly lenticular as they are at Studley Park. We may exclude normal sub-aqueous gliding from consideration because all the minor deformations now under discussion are localized within single strata as units. In sub-aqueous gliding groups of strata are affected together. Hadding (1931, pp. 380-1) has expressed the germ of the idea that readjustments along bedding planes may take place during compaction, but he classifies mudstone injections almost identical with those indicating movement along bedding planes at Studley Park and elsewhere in Victoria, as resulting from sub-aqueous sliding. The two phenomena are, however, essentially different. Bedding-plane slip is also developed during tectonic deformation, and when it is remembered that such movements will commence during the early stages of deformation, the difficulty of distinguishing pre-tectonic and tectonic movements will be obvious. So far no criterion has been discovered that might enable a distinction to be drawn, but the virtual restriction of the mudstone injections to the bases of sandstones, and the evidence for great mobility in the latter that the structures afford, strongly suggest that they are pre-tectonic.

It should be realized that this interpretation is of a preliminary nature; further investigations of similar structures in other districts are being carried out. Already, however, it is possible to indicate that, owing to the virtual restriction of the flowage and injection phenomena to the bottom surfaces of sandstone strata, they can be of considerable use in structural mapping. A further result of the present investigations in this connexion is that in thin sandy strata showing current-mark, where the presence of the complete curve of current-bedding greatly restricts the use of current-bedding as an indicator of the order of superposition of inclined strata, the flat base of the current-marked beds, as contrasted with the waved upper surface, can in many cases readily be distinguished.

The occurrence of true sub-aqueous gliding in the Silurian rocks might be suspected from the presence of marked intra-formational disturbance in places, but the strong shearing, brecciation, and folding of mudstones and thin sandstones lying between more massive strata, seen on the west face of the cliff at Dight's Falls and in the outlet to the Riley Street drain, are of tectonic origin, as is shown by the development of cleavage in the mudstones at the latter locality, and the slickensiding of adjacent massive strata at Dight's Falls.

Origin of Major Structures.

Reverse Faulting.

Although the average strike of the reverse faults is 170°, i.e., making an acute angle with the general trend of the axial lines, it is more significant that the faults in the south of the area (fig. 4A) strike, on the average, parallel to the axial lines in this part, while where the axial lines change their trend in the north, the faults change sympathetically in strike (fig. 4B). It, therefore, appears that the faults and the folds are genetically related. The total vertical distance available for study in the district is, however, so small compared with the magnitude of the major anticlinorium involved that it would be unwise to draw any further conclusions as to the mechanics of formation of the faults in general.

Some examples, however, are of purely local significance. On the north face of the cliff at Dight's Falls, for instance, sandstones and mudstones interbedded between massive sandstones exhibit small-scale incipient imbricate structure with low-angle thrust faults, formed as a result of differential shearing movements of the beds on either side.

Folding.

Throughout the district, no significant recrystallization of the Silurian rocks has occurred. So far as could be ascertained without the aid of a universal stage, the quartz grains show no marked preferred orientation, and no strain effects even in folds with a radius of curvature of an inch. The plasticity of the strata was therefore not that of a crystalline material, and the folding must have involved only external grain rotation, slip along sedimentary and tectonically developed S surfaces, and positive and negative dilatation. Certain of the sandstones have also yielded by fracture. The mudstones remained capable of flow throughout the folding and faulting; they filled up the spaces formed by the fracturing of the sandstones, and also flowed into the fold apices between the sandstone strata (fig. 10). The sandstones themselves are thickened at the fold apices, measured examples showing two beds thickening from 2½ inches to 3 inches, one from 3 inches to 3½ inches, and one from 6½ inches to 8 inches. These differences in thickness are most probably due to lateral compression, which would result in thinning of the highly inclined limbs and expansion at the apices, the volume changes being brought about by reduction in the percentage of pore-space, and re-arrangement of the grains. This indicates, in the absence of grain deformation, that the grains were not firmly cemented before folding occurred, and, therefore, that the rocks had not been so deeply buried as to have had their pores closed by compaction and recrystallization, or so impregnated with secondary minerals as to have been cemented by infiltration.

The manner of development of shear thrusts, described above, indicates a similar irreversible dilatation of the strata, measured examples on seven faults indicating an average reduction in thickness by 1 in 20 (see fig. 8). Two of these examples gave 1 in 19, two 1 in 20, and one 1 in 22, so the average figure is probably significant.

The expansion of sandstones at fold apices also suggests that the local strain ellipse within a particular sandstone stratum, in a plane transverse to the apex and containing the axis of the fold, had its longer diameter vertical. That this was so for the observed sandstones (apices for the massive sandstones at Dight's Falls are not visible) is indicated by one bed that was not capable of sufficient expansion, and yielded by fracturing as is fig. 10B (bed *b*). This fact indicates that not only was the strain ellipse along each fold axis (including many strata) vertical, as is indicated by the flow of mudstones towards the fold apices, but, within each stratum, neutral surface folding (Ickes, 1923), did not obtain. Evidently no stratum was sufficiently competent to have acted as a thick plate, capable of lifting the overlying beds. The major stress components within each bed at the fold axes where bedding-plane slip is *nil* were essentially parallel to the regional compressional forces. The sandstones yielded by bedding-plane slip along stratification planes as well as along bedding planes, aided by grain rotation. The importance of bedding-plane slip in thick sandstones is admirably illustrated by the Victoria Bridge anticline, on the river east of "Raheen", where the uppermost laminae of a sandstone bed have been able to slip further than those lower down, and have been raised into a very small subsidiary anticline on the crest of the larger. The conclusion is reached, therefore, that the folding involved—

(*a*) flowage of mudstones towards fold apices;

(*b*) bedding-plane slip, and slip along stratification planes in laminated sandstones;

(*c*) thinning of strata in fold limbs, and thickening at apices, by lateral compression.

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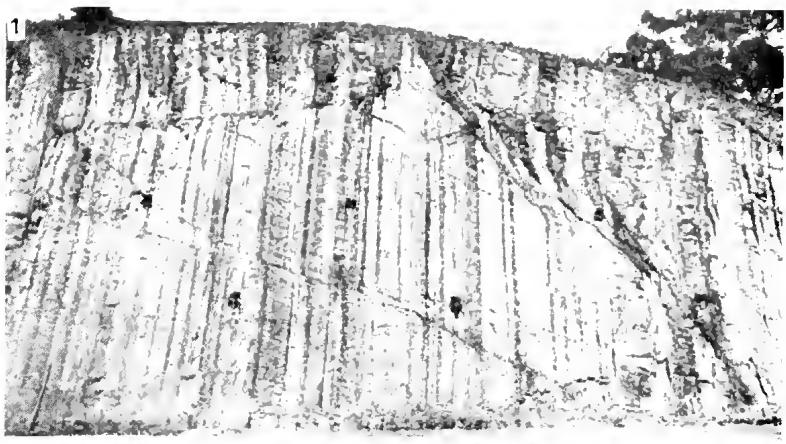

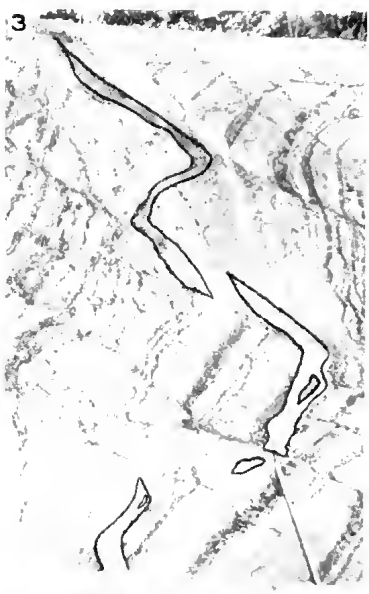

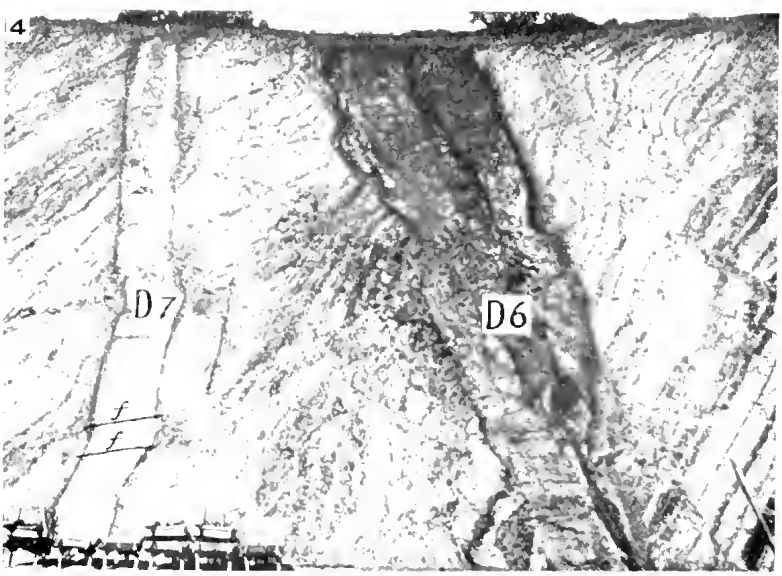

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Explanation of Plate.

Plate V.

Fig. 1.—Reverse faulting and shear jointing in Silurian sandstones and mudstones. Location: about 1 ch. mark, profile *EF*.

Fig. 2.—Portion of Fig 1, enlarged to show relation between reverse fault *g* and shear joints.

Fig. 3.—Dyke D5 (see profile *CD* at 8½ ch.), showing the way in which the dyke follows pre-existing planes of weakness.

Fig. 4.—Dykes D6 and D7 (see profile *CD* between 7 and 8 ch.). Note the apparent displacement of the lower part of D7 by post-dyke faulting at *ff*, and the inhomogeneity of D6.

H. S. Mann, photo.

[Proc. Roy. Soc. Victoria, 53 (N.S.), Pt. 1., 1941.]

Art. V.—*A Bacterial Disease of Stocks caused by* Phytomonas matthiolae.

By ROSE MUSHIN, B.Sc.

[Read 13th June, 1940; issued separately 1st February, 1941.]

Introduction.

Early in September 1938, a disease of stocks (*Matthiola incana* R. Br. var. *annua* Voss.) was reported from Brunswick Park, Victoria. The stocks showed a high percentage of diseased plants distributed in large patches amongst the healthy ones. Enquiries revealed that the disease became evident in August and with the warmer weather conditions did not spread to neighbouring plants.

The bacteria causing diseases of stock can be divided into two groups. One comprises *Bact. campestre* (Pammel) E. F. Smith and bacteria closely related to it as recorded by von Faber (13) in 1907, Cooley (12) in 1932, Kendrick (17) in 1938 and by Wilson (30) in New South Wales in 1938. The organism described in this work belongs, however, to a second group of green fluorescent bacteria.

Briosi and Pavarino (4) in 1912 first reported a green fluorescent organism causing a disease of stocks in Italy and named it *B. matthiolae*. They described the symptoms and the morbid anatomy of the attacked plants, but no critical account of the organism was given. Rudorf and Job (24) in 1932 observed a similar disease and on the basis of external symptoms and histological studies concluded it to be caused by *B. matthiolae*. Adam and Pugsley (1) in Victoria in 1934 recorded the occurrence of a disease of stocks due to a green fluorescent bacterium but thought it distinct from the one reported in Italy. In 1937 a disease of stocks was observed on the Italian Riviera (23) reported to be caused by *Bact. matthiolae*. Burkholder (8) suggested that *B. matthiolae* is identical with *Phytomonas syringae*, as inoculations of stock plants with the latter organism produced symptoms similar to these described by Briosi and Pavarino and by Adam and Pugsley.

Observing that no detailed account of the organisms described by the above-mentioned writers was supplied, it seemed advisable to make a study of the disease brought under notice.

Symptoms.

The diseased stocks observed in the field in the earlier or milder stage of the attack showed light green spots on the leaves. At a later stage the leaves became discoloured, pale green, with

scattered dark green spots and an uneven surface presenting a puckered appearance. Badly affected plants were dwarfed, the leaves small and deformed with incurled margins, the flowers discoloured and under-developed. In some instances it was noticed that the stems became woody and new lateral shoots sprang up which were stunted, carried deformed leaves and flowered poorly. Some stems showed dark brown streaks or splits and the cortex was discoloured. To the naked eye the roots appeared normally developed.

Isolation.

In the early stages of the disease the plants often yielded a pure culture of the pathogen, while badly infected plants usually showed invasion by secondary parasites. The infection being systemic, isolations were made from any part of the stem or leaves and pure cultures were used for inoculation tests.

Inoculation Studies.

To test the pathogenicity of the organism isolated, 24 hr. cultures on agar slopes emulsified with a few c.c. of sterile water were used for inoculations. A few sets of inoculation experiments were performed. In the first set in September, 1938, three horticultural varieties of stocks were used: Imperial, Ten Weeks and Nice. The last named proved to be most susceptible to infection. Seedlings were inoculated, the procedure adopted being to place them in moist chambers for 24 hours before and after the inoculation. Out of six stock plants of Nice variety two were treated as control. Two inoculated by puncturing the stem developed local necrotic lesions, causing splitting of the cortex and stunting in growth. Two others were inoculated by pricking the leaves with a charged needle and one of them displayed within one week light green roundish spots about 2 mm. in diameter, followed by puckering of the leaves while the other showed only small brownish lesions around points of inoculation.

Later inoculation tests were made with pure cultures re-isolated from the artificially infected stocks. These tests were performed on plants of different ages and under varied conditions by puncturing the stem or leaves with a charged needle or by spraying. In most cases infection was obtained but the symptom picture was different, probably due to temperature and humidity changes, as no facilities for maintaining constant environmental conditions were available. Evidence pointed to the conclusion that young seedlings kept under lower temperatures were most badly affected. Sometimes only local brownish lesions were produced on stems and leaves, these later becoming puckered. In other cases irregular light green spots appeared on the leaves not only around points of inoculation but scattered irregularly. Dwarfing and deformation of leaves was produced most often by inoculating the stems of young seedlings. Hand cut and

microtome sections of the infected stocks showed the presence of bacteria. Numerous re-isolations of the organism were carried out and the green fluorescent bacterium was identified by means of cultural and biochemical characters.

Morbid Anatomy.

Plants which had been infected both naturally and experimentally were used for the purpose of obtaining material for hand-cut and microtome sections. Staining of the preserved tissues with Loeffler's methylene blue for 10-15 mins. and subsequent decolourisation with 0.5 per cent. acetic acid gave satisfactory results. The bacteria were found in the parenchymatic cells and the vascular vessels, which were often blocked either by bacteria or a brown exudate. In advanced stages of the disease the tissues showed cavities filled with bacteria. The roots were less susceptible to invasion than the aerial parts of the plants.

Cross Inoculations.

Smith (28) considered the Italian stock disease caused by *B. matthiolae* to be similar to the Dutch disease of wallflower, of which no complete account was given. Burkholder (8) pointed out the similarity in the description of the stock organism and *P. syringae*. A survey of literature indicated the desirability of experimental inoculation of tobacco and tomato as some other members of the genus Phytomonas (Burkholder (6), (9)) are able to infect plants of the Solanaceae and Cruciferae families, producing leaf spots, e.g. *P. tabacum* (Wolf and Foster (16)) or *P. vesicatorum* var. *raphani* (White (29)), resembling *P. campestre*. Also simultaneous biochemical studies proved the stock organism to be similar in its characters to *P. polycolor* (11), causing leaf spot on tobacco (Clara (10)) and to *P. marginale* (11), infecting lettuce (Brown (3)).

Cross inoculations with the organism re-isolated from the experimentally infected stocks were made to wallflower, lettuce, lemon fruit, tobacco and tomato plants. The method of cross-inoculation was similar to the one applied for infecting stocks. The results are given in *Table* 1.

Table 1.

Type of Plant.	Cross Inoculations.
Lemon fruit	No symptoms of infection.
Wallflower	Stem inoculations produced brown necrotic lesions; leaf punctures caused puckering and sometimes a slight deformity.
Lettuce and Tomato	Stem and leaf inoculations produced small brownish lesions around points of inoculation.
Tobacco	Stem inoculations caused slight necrotic lesions; around the leaf punctures lighter coloured zones were noticeable.

Attempts to re-isolate the stock organism from lemon fruit were unsuccessful. Isolations made 10 days after inoculations from the edge of lesions of wallflower, lettuce, tomato and tobacco plants resulted in obtaining cultures of the green fluorescent bacterium, identical with the one used for inoculations. No dwarfing or deformity of plants was observed at any later date. Isolations made from parts of the plants at some distance from the points of inoculation did not yield the bacterium.

These experiments indicated that the organism could survive in the cells of the host plants mentioned but was not able to produce systemic infection.

The Causal Organism.

Pure Culture Studies.

The technique adopted—unless otherwise stated—was in accordance with the methods recommended by the Manual of Methods for Pure Culture Study of Bacteria (Society of American Bacteriologists).

Morphology.

The morphology and size of the cells was obtained by observing smears treated by Benian's method with congo red. The cultures were grown on beef extract agar of pH 6.8 for 24 hours at 24° C. A colony on agar plate of the organism freshly isolated from stock consisted of cocco-bacilli of 0.75 x 1.0μ in size, or small rods with rounded ends whose length did not exceed 1.8μ. The bacteria occurred singly or in pairs. A smear from an agar slope culture showed rods with rounded ends, some straight, others slightly bent 0.75–1.1μ x 1.3–3μ in size. The cells were distributed singly or in pairs. Older laboratory cultures consisted usually of longer rods than the younger ones and often had chains 7μ to 35μ in length, in which the division into cells was not clear.

Bacteria from a 24 hour old broth culture under dark ground illumination appeared as cylindrical rods, many paired together, some in short chains, displaying a swift darting movement across the field. Flagella were demonstrated by staining the smears from a 24 hour old agar culture by Cesares-Gil's method, using the mordant in 1 : 1 dilution and carbol fuchsin for 5 minutes. The flagella were polar, one or two in number. A few cells showed bi-polar flagella having one flagellum at each end of the cell or one at one end and two at the other; these cells might have been in the process of division as a slight constriction in the middle was noted. The flagella were wavy and longer than the cells.

The bacteria from a 24 hour old agar growth stained evenly using a simple stain, while in older cultures some cells stained deeper in contrast to other faintly stained ones. The organism proved to be Gram negative, not acid fast and non-sporing. No capsules were demonstrated by the methods of Hiss or Anthony.

Cultural Characters.

All cultures were incubated at 24°C.

Agar Colonies.—A 24 hour old agar plate of the freshly isolated organism displayed punctiform and circular colonies 1-2 mm. in diameter. Some reached 4 mm. after a few days of incubation. The colonies were smooth with an entire edge, raised and translucent, showing a brownish tint in transmitted light. The plates had an unpleasant odour. A poured plate from a laboratory culture showed after two weeks of incubation circular colonies 6-7 mm. in diameter with a greyish inner circle 5 mm. in diameter, containing a thick point in the centre and a translucent and striated ring outside the circle. Amongst the colonies some were found with a lobated edge, rather flat, translucent, often possessing an outer striated ring.

Agar Stroke.—An abundant growth appeared after 24 hours of incubation, filiform with a slightly undulate margin, glistening, of butyrous consistency, producing a greenish colouring of the medium. After three days the green colouring became more distinct and the edge of the growth looked like a fine scalloped trimming. Later the medium turned light brown. Older laboratory cultures exhibited a less distinct green pigment which became more intense on rejuvenating the bacteria by passage through broth and through a few quick successive transfers to fresh agar slopes. The freshly isolated cultures had an unpleasant odour which became less offensive with age.

Agar Stab.—Growth occurred along the line of inoculation reaching the bottom of the tube.

Nutrient Broth.—Twenty-four hour old cultures showed strong turbidity. Clouds were raised on shaking. No pellicle or sediment was visible. After 48 hours the clouding became deeper, so that print could not be read through it. At the surface of the cultures, at points of adhesion to the walls, a ring of granulated growth was noticed. In a few days a creamy sediment settled on the bottom of the tube while on the surface a very delicate pellicle was formed, easily detached by a slight disturbance. Often the surface displayed no pellicle, only a ring of granulated growth. A green fluorescent zone appeared at the upper part of the broth and gradually diffused into the medium.

Gelatin Stab.—At 20°C. in 24 hours the growth was best at the surface, the line of puncture being filiform with an initial drop of liquefaction, starting at top. In four days the liquefaction became infundibuliform and spread to three-quarters of the medium. The liquefied area took on a green colouring, displaying a pellicle and a sediment. In six days the gelatin was liquefied from wall to wall reaching almost to the bottom of the tube.

Milk.—In 24 hours a ring of digestion appeared at the surface. In five days one-third of the medium was digested and became greenish. In eleven days half of the medium was watery,

greenish, and turned alkaline, while a soft creamy coagulate settled down. In twenty days the medium was cleared, greenish with a yellowish coagulate down the tube.

Litmus Milk.—During the process of reduction of litmus many changes in colour took place, which were named according to Ridgway's classification. In the course of many observations it became evident though, that the occurrence of different shades was not constant, and in consequence a crude naming of the colours seemed most reasonable.

In 24 hours a slight ring of digestion appeared at the surface of the medium. In 48 hours a lower ring of discolorization became visible. In three days a soft coagulate started to form at the bottom of the tube. In five days one-third of the medium was digested and yellowish in transmitted light. In eight days this yellowish colour had a green tint. In twelve days the medium was digested and the reaction became alkaline. In one month in transmitted light the yellow digested medium had a distinct green tint, in two months it became brownish-red. In three months it took on a beautiful wine colour, while in reflected light it looked dull blackish-green, and the coagulate a dirty greenish colour.

Brom Cresol Purple Milk.—In 24 hours a zone of digestion appeared on the surface of the culture and progressed toward the bottom of the tube taking on a purplish tint. In eleven days the milk became distinctly purple in transmitted light; the medium was alkaline with a coagulate at the bottom of the tube.

Potato Medium.—An abundant moist light-brown growth was produced after 48 hours of incubation. The medium turned a darker shade.

Uschinsky's Solution.—Good growth, sediment and a firm pellicle. The medium turned brilliant green, starting with a zone at the surface.

Fermi's Solution (Tanner's variant).—Growth at first was less vigorous than in Uschinsky's solution, with a firm pellicle and sediment. Colouring was less distinct than in Uschinsky's medium.

Cohn's Solution.—No growth.

Sullivan's Solution.—(Clara (10).) showed constantly green fluorescence.

Physiological Characters.

Relation to Free Oxygen.—This was determined by growing the organism in agar shake cultures and on agar slopes under anaerobic conditions, when a scanty film of growth was formed. The bacterium proved to be a facultative anaerobe.

Action on Nitrates.—A reduction of nitrates to nitrites without gas production was observed in 24 hours. In 48 hours a complete

consumption of nitrate beyond the nitrite stage took place and ammonia was liberated. Parallel control tests were conducted with sterile nitrate broth media and *Escherichia coli* cultures.

Production of Ammonia.—For this test Hensen's (15) method was adopted. Ammonia production was detected in peptone broth cultures of pH 7.6 incubated for three days. A sterile medium was tested and proved to be ammonia free.

Indole Production.—Two and seven days' old peptone cultures were tested by the Ehrlich-Böhme technique. No indole was detected. *Esch. coli* cultures were used as controls.

Hydrogen Sulphide Production.—The lead acetate strip technique was adopted. No hydrogen sulphide was detected. *Esch. coli* cultures were used for comparison.

Hydrolysis of Starch.—Starch broth media were used according to Eckford's method. After ten days a partial hydrolysis took place, indicating the production of erythrodextrin. After six weeks of incubation the digestion of starch did not progress further, and no sugar was detected at any time with Fehling's solution.

Cellulose digestion was tested as described by Clara (10). None was recorded.

Utilization of Amino-acid Media.—The formula of Frazier and Rupp (14) was followed by adding different amino-acids to a basic mineral solution. Good growth was recorded in peptone, asparagin, and aspartic acid, weaker in glutamic acid and tyrosin, showing the ability of the organism to derive its carbon and nitrogen requirements from the above-mentioned amino-acids.

Carbohydrate Reactions.

Two kinds of media were prepared. One set contained media with a peptone base and an addition of 1 per cent. of various carbohydrates, sterilized by steaming on three successive days. One per cent of Andrade's indicator was added and the reaction was adjusted to pH 6.8. These media were provided as additional means of quick identification by biochemical reactions of the organism isolated from infected or artificially inoculated plants The results are given in Table 2.

Table 2.

Carbohydrate reactions (in peptone media).

Glucose.	Galactose.	Lactose.	Sucrose.	Maltose.	Mannite.	Glycerin.	Salicin.
+	−	−	−	−	−	−	

+ = acid. − = no acid, no gas.

Acid was recorded only in glucose and galactose after three days of incubation, while older laboratory cultures took a longer time to ferment these sugars.

The second set of media contained a peptone free base with an addition of various carbohydrates: sugars, alcohols, glucosides or organic acids. These media were made up by following Burkholder's (8) directions. To avoid any changes by heating of the media, all sugar solutions were passed through a Seitz filter. To record acid production brom cresol purple was used as an indicator, while phenol red was utilized to note any change to alkalinity in the organic acid media. The cultures of the stock organism used for inoculation of media were derived from the two morphologically different kinds of colonies found on agar plates, namely, the entire and the lobated edge types. Both of them gave identical biochemical reactions, recorded in the table below:—

TABLE 3.

Carbohydrate reactions (in peptone free media).

(1) *Acid produced* in:—
Rhamnose, glucose, levulose, galactose, mannose, glycerol, mannite, acetic acid, citric acid, formic acid, lactic acid, malic acid, succinic acid.

(2) *Feeble acid* production in:—
Maltose.

(3) *No acid, no gas* produced in:—
Lactose, sucrose, raffinose, starch, salicin, tartaric acid.

All fermented cultures displayed a distinct change of colour within six days of incubation, except rhamnose, which was more slowly fermented. Maltose was discoloured after three weeks, indicating only feeble fermentation.

TEMPERATURE RELATIONS.

Freshly inoculated agar and broth cultures were incubated at different temperatures and the influence on growth was noted.

TABLE 4.

Temperature Relations.

Temperature C.	Growth	Colour of Medium
0	Fair	No change
10	Fair	Sometimes slightly green
20–24	Abundant	Distinctly green
30	Good	No change
37	Slight	,,
38·5	Little or none	,,
41	None	,,

Motility was most active in 24-hour-old broth cultures incubated at temperature between 10°C.–30 C. After three days the bacteria became sluggish. A pellicle or a granulated zone was

formed at the surface of broth cultures at temperatures between 10°C.–30°C., not observed at 0°C. or 37°C. It is interesting to note that cultures kept for a week at 0°C. or 37°C. and then transferred to an incubator at 24°C. or transfers made from cultures kept at 0°C. and 37°C. to media placed at 24°C. resulted in the production of an unusually brilliant green fluorescence.

Thermal Death Point.—This was determined by applying Magoon's capillary method. Nineteen-hour-old broth cultures were used for the test. 52°C. for ten minutes proved to be the thermal death point.

Relation to Reaction (pH) of Medium.—One loopful of a 24-hour broth culture was transferred to extract-beef broth media of different pH values, starting from pH 4.0 and reaching pH 10.0. On the acid side pH 4.4 proved to be the limit for growth, and pH 9.5 on the alkaline side. These limits of growth are in agreement with the ones estimated by Berridge (2). At these pH values the broth tubes showed only slight turbidity after 48 hours of incubation. Most distinct fluorescence of the medium took place at pH about 7.4 and seemed to be more pronounced on the alkaline side, still showing a diffused green colouring at pH 9.1. On the acid side pH 5.4 represented the limit line for the production of green fluorescence, and only a greenish zone was formed at the surface.

Effect of Desiccation.—This was determined by placing drops of 24-hour-old broth cultures on sterile coverslips and letting them dry (Smith (26)). No growth appeared after seven days of desiccation.

Effect of Direct Sunlight.—This was determined by following the method described by Smith (27). The test was carried out in the beginning of March about noon. Growth was obtained after an exposure of fifteen minutes, while no growth was recorded after an exposure of 30 minutes.

Vitality in Culture Media.—The organism was still alive in agar, milk, and gelatin cultures eight months' old, left at room temperatures. Eleven months' old agar and potato cultures were dry, and the bacteria proved to be dead.

Conclusions.

The described organism is considered to be identical with the one reported by Briosi and Pavarino (4), and named by them *Bacterium matthiolae*. The symptoms of plant infection, the inoculation tests, and the biochemical reactions of the organism prove it to be different to the one recorded by Adam and Pugsley (1) and not identical with *Phytomonas syringae* (8).

The organism belongs to the genus *Phytomonas* (6), so the proper name is *Phytomonas matthiolae*. A comparison with the green fluorescent bacteria listed by Clara (10) would include the

organism in the sub-group II. of the non-sucrose fermenters composed of soil saprophytes and weak plant parasites. This statement finds confirmation in the inability of the bacterium to attack all strains of stocks, and in the fact of the disease being checked easily by less suitable weather conditions.

The cultural and physiological characters of *P. matthiolae* show an affinity to *Pseudomonas fluorescens* (Flügge) Migula and to *P. aeruginosa* (Schröter) Migula (which is a synonym to *B. pyocyaneus* (Gossard)). Ruzicka in 1898 (25) considered *B. fluorescens* and *B. pyocyaneus* closely related, the difference in characters being due to the adaptation of *B. pyocyaneus* to a parasitic existence and of *B. fluorescens* to a saprophytic mode of living. Niederkorn (21) in 1900 stated that amongst the fluorescent bacteria only two constant forms are to be found, namely, *B. pyocyaneus* and *B. fluorescens*. With the advance of scientific work much data was collected indicating the close relationship of the green fluorescent bacteria (Burkholder (6), (9); Clara (10), (11); Lacey (18), (19)). It is interesting to note here that one of the non-sucrose fermenters *P. marginale* (Brown) was considered by Metha and Berridge (20) to be identical with *B. pyocyaneus*. In the light of recent research (22) thrown on the subject members of the *Phytomonas* group causing leaf-spot diseases are considered to be physiological adaptations of *Pseudomonas fluorescens*.

Short Description of *Phytomonas matthiolae*.

Small Gram −ve rod, occurring singly or in pairs, chains sometimes formed. Size 0.75 − 1.1μ × 1-3μ. No spores, no capsules. Agar colonies with entire or lobated edge. Growth on agar slope and in broth abundant, producing green fluorescence. Fragile pellicle in broth. Gelatin liquefied. Milk alkalinized, coagulate formed, litmus reduced. Growth with green fluorescence in Uschinsky's, Fermi's and Sullivan's solutions, none in Cohn's. Facultative anaerobe. Production of ammonia +ve, indol −ve, hydrogen sulphide −ve, cellulose digestion −ve, starch feebly hydrolyzed. Amongst peptone carbohydrate media glucose and galactose are fermented without gas production, while lactose, sucrose, maltose, mannite, glycerin and salicin are not fermented. Amongst peptone-free carbohydrate media rhamnose, glucose, levulose, galactose, mannose, glycerol and mannite also acetic, citric, formic, lactic, malic and succinic acid are fermented without gas production. No acid or gas is recorded in lactose, sucrose, raffinose, starch, salicin and tartaric acid. Maltose is feebly fermented. Optimum temperature 20-24°C., minimum below 0°C., maximum slightly above 38.5°C. Thermal death point 52°C. for 10 minutes. Limits of growth in broth are pH 4.4 to pH 9.5. Best fluorescence at optimum temperature at about pH 7.4. The limit for desiccation is 7 days, for direct sunlight exposure 30 mins.

Summary.

An investigation was conducted on a disease of stocks which was reported in Victoria in 1938. The disease was proved to be caused by *Phytomonas matthiolae* originally recorded by Briosi and Pavarino in Italy, but not observed hitherto in Australia. Artificial infections were successful with healthy stocks of Nice

var., and cross inoculations were attempted. A pure culture study with full details was conducted and data on morphological, cultural, and physiological characters of the organism were secured.

Acknowledgments.

This work was carried out at the Botany School of the University of Melbourne, and thanks are expressed to Professor J. S. Turner for the facilities provided.

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Explanation of Plate.

Plate VI.

Fig. 1.—A patch of diseased stocks with the healthy plants in the background.

Fig. 2.—Left: Healthy Control.
Right: Stock infected artificially by stem inoculation.

[Photos. M. Rothberg.]

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Art. VI.—The Granites of the Terricks Range and Lake Boga, in Northern Victoria.

By EDWIN SHERBON HILLS, Ph.D., D.Sc.

[Read 11th July, 1940; issued separately 1st February, 1941.]

Introduction.

In the district between Mitiamo, Terrick-Terrick, Pyramid Hill, and Mt. Hope in County Gunbower, groups of low granitic hills rise above the almost featureless alluvial plains of the Northern District. The Terricks Range, which extends northwards from Mitiamo and terminates north-east of the outstanding landmark formed by the conical peak of Pyramid Hill, constitutes the main granitic terrane, but outlying hills such as Mt. Hope extend the area in which granites occur to over 60 sq. miles. The most southerly outcrop, at Mitiamo, is nearly 40 miles distant from the northern boundary of the Central Highlands (see Physiographic Map of Victoria in Hills, 1940), and as no exposure of the country rock that was invaded by the granites has been observed, direct evidence of their age is not available.

The boundaries of the granites were mapped by the Geological Survey during the preparation of the 1908 edition of the geological map of the State, and the map accompanying this paper (fig. 1) reproduces the data from the original survey in more detail. Major Mitchell, who ascended Mt. Hope and Pyramid Hill in 1836, gives sketches of both these hills, and states that the rock is granite (Mitchell, 1835, Vol. II., pp. 155-9). Brief remarks on the physiography of the district, illustrated by aerial photos, have already been published by the present author (Hills, 1940, see Index), but no account of the petrology of the granites has previously appeared.

The granitic outcrop at Lake Boga in County Tatchera occupies a small area (of the order of 1 sq. mile) about 7 miles south of Swan Hill. It is 50 miles distant from the northern boundary of the Central Highlands, 45 miles from the isolated granite knoll at Wycheproof, and about the same distance from Pyramid Hill. The location of the occurrence is incorrectly shown on the 1908 geological map (8 miles to 1 inch), but has been correctly represented on maps of north-western Victoria previously published by the author (Hills, 1939, fig. 1; 1940, fig. 321, p. 243). I am indebted to Mr. W. Baragwanath for the use of MS. maps of the Terricks Range and Lake Boga, on which my published maps and field work have been based, and also to Mr. G. Baker for heavy mineral analyses of the rocks whose Index Numbers are given below.

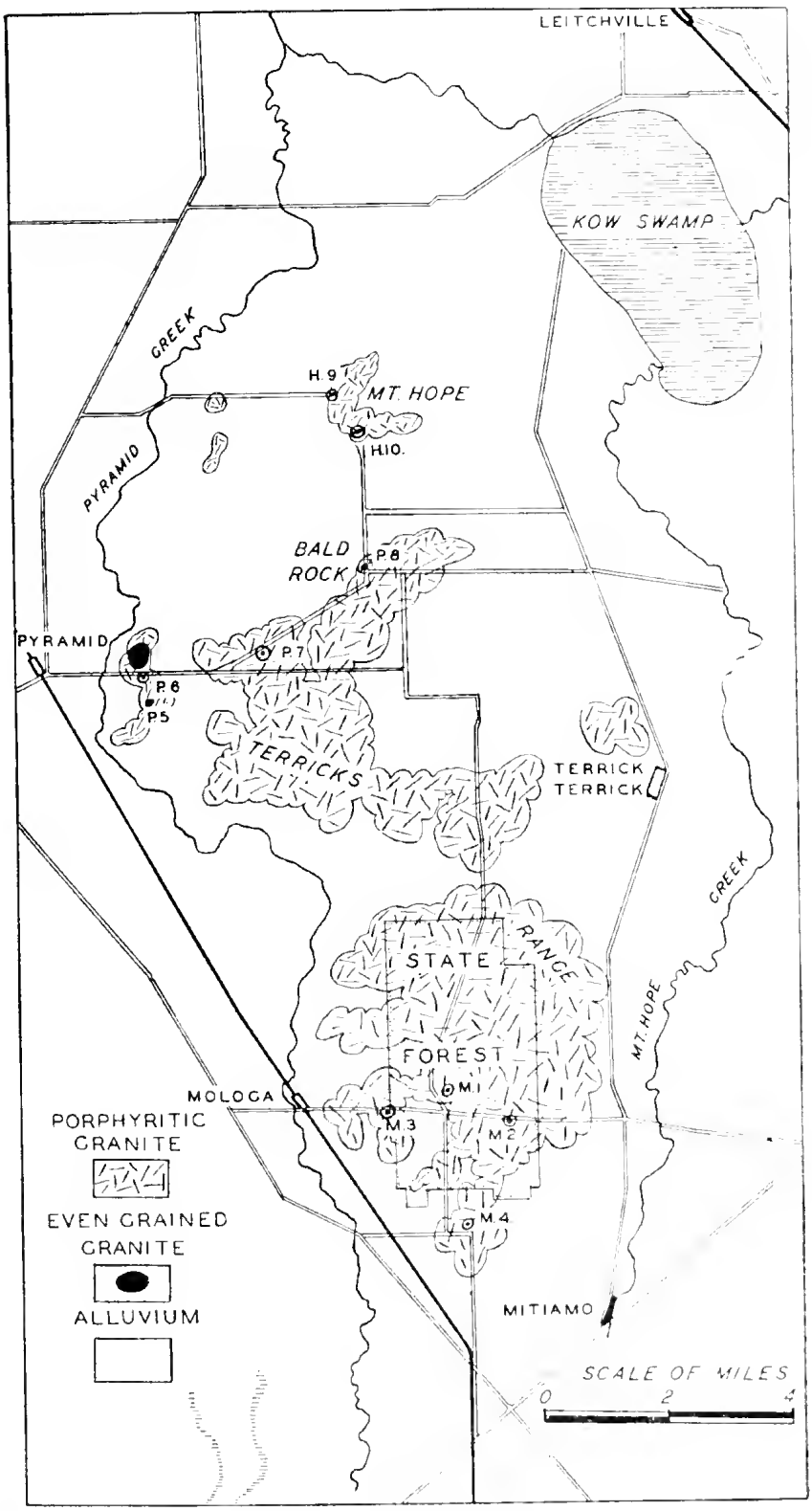

FIG. 1.—Geological map of the Terricks Range.

[Page 267.]

The Granites of the Terricks Range.

Field Occurrence.

The granites of the Terricks Range and neighbouring districts outcrop as tors and bare rock faces at and near the summits of knolls that rise abruptly from marginal alluvial fans, these emerging gradually into the surrounding alluvial plains (fig. 2). Fresh specimens of the granite are only rarely obtainable from natural exposures, for the rock is generally weathered to a considerable depth, in such a way that, though it may remain intact, boulders will shatter under the hammer. This results from loss of cohesion between the mineral grains owing to insolation, followed by the deep penetration of weathering agents along minute cracks.

Fig. 2.—Pyramid Hill, from the north. Note the abrupt change from the rocky hill-sides to the smooth contours of the surrounding alluvial fans.

All the granites in this district, with the exception of that of which Pyramid Hill is composed, are of porphyritic habit, containing large white phenocrysts of micro-perthite averaging about 1½ inches in length, also smaller phenocrysts of quartz, felspar, biotite, and subordinate muscovite, with a minor amount of granular, leucocratic, interstitial base. The Pyramid Hill granite is, however, even-grained, consisting of cream or white microperthite, quartz, biotite, and abundant muscovite.

At many localities the perthite phenocrysts show a definite parallelism, with their long axes orientated east-west (fig. 3), but this regular arrangement is not found in all parts. The proportion of phenocrysts to groundmass also shows considerable variation, some patches of a few square yards being non-porphyritic, other small patches crowded with phenocrysts, as in the new quarry at the foot of Pyramid Hill. At Mitiamo (Loc. M.2)—see map for localities mentioned—also at the new Pyramid Hill quarry (Loc. P.6) and nearby at Loc. P.7, biotite-rich schlieren of undulating habit occur, associated with patches of granite crowded with perthite phenocrysts, some of which project into the schlieren, in a manner resembling that described by Baker (1936) at the You Yangs. Xenoliths are rare in most parts of the district, but a few were obtained from Mitiamo (Loc. M.3), also from Pyramid Hill at Locs. P.6 and P.7. The xenoliths are fine-grained biotite-rich types, some of which contain porphyroblasts of felspar.

Aplites, quartz porphyries, pegmatites, and graphic granites occur as narrow dykes or veins in many parts, but all these

differentiates are very subordinate in volume to the granites. The dykes and veins typically follow joint planes, especially the nearly vertical east-west joints, with which the flow lines revealed by the micro-perthite phenocrysts are parallel. Approximately vertical north-south joints and flat-lying joints are also well developed, the latter often determining the occurrence of extensive bare rock faces, or pediments on which tors rest.

Owing to the absence of other hard rocks in the district, the granites are of considerable economic importance as a source of broken stone for road construction, concrete, and other purposes. Quarries have been opened at Pyramid Hill, but the readily-worked superficial quartzo-felspathic rubble and rotten rock developed by weathering are also extensively used on the roads.

Petrology.

1. Porphyritic (Giant) Granite.

Micro-perthite phenocrysts as large as $2\frac{3}{4}$ in. by 2 in. by 1 in. were observed, but the average length is about $1\frac{1}{2}$ inches. The crystals are tabular parallel to the clinopinacoid, other commonly developed faces being the unit prism, basal pinacoid and hemiorthodome (201). Interpenetration Carlsbad twinning is almost universal. Orientation: *c* axis usually east-west; (010) approximately parallel to the flat-lying joints (fig. 3).

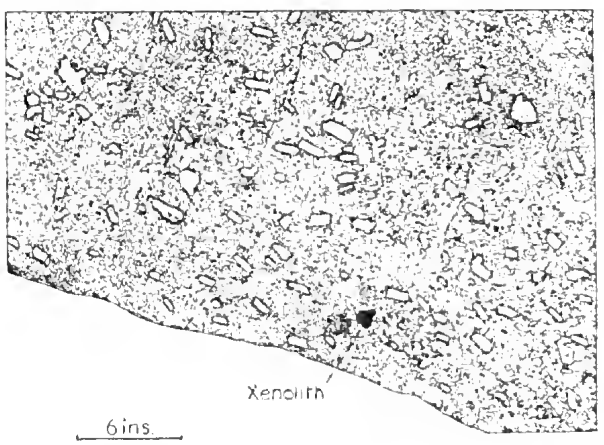

Fig. 3. Sketch of a vertical face of granite at Mittamo, showing the alignment of fel-par phenocrysts parallel with the flat-lying joint that terminates the face below.

Inclusions are common in the larger perthite phenocrysts. These include sub-rectangular oligoclase crystals showing composition zoning, usually with a sharply-defined outer acid coating or "jacket" (Ab. 85), and a more basic core (Ab. 70). Biotite

and quartz are also included in the perthites, especially in the outer parts of large phenocrysts. Typically, the included minerals are arranged in zones, evidently having been incorporated at certain stages during the growth of the perthite phenocrysts. Many of the latter exhibit composition zoning, and the composition zones are parallel to the lines of inclusions. This zoning is shown by variations in the distribution of fine ex-solution lamellae, as in the potash-felspars described by Trefethen (1937) and Spencer (1938), and is of an oscillatory nature.

The majority of perthites exhibit both the "vein" type of perthite lamellae, and the very fine ex-solution lamellae or threads. The arrangement of the "vein" and ex-solution lamellae is different, as is well shown in slide [5690]. (Note: Numbers in brackets refer to slides registered in the Geology Department, University of Melbourne.) This is cut parallel to (010), and shows the two individuals of an interpenetration Carlsbad twin. The "vein" perthite lamellae are parallel to the vertical axis *c*, but the ex-solution lamellae make acute angles with *c*, the largest deviation (11 deg.) agreeing with the angle of the negative hemiorthodome ($\bar{6}01$). There appears to be no sharp demarcation between the "vein" and ex-solution lamellae (fig. 4E), which grade into each other, especially at the terminations of the "veins".

Slide [5694] illustrates a commonly occurring phenomenon. Along the borders of each "vein" perthite lamella, the host felspar is raised in double refraction to .007, it extinguishes at 9° on the (010) plane, and shows indistinct cross-hatching. In many other examples, as is illustrated by [5711], this apparently triclinic modification is also exhibited, and the cross-hatching is well-developed. The felspar cannot be anorthoclase because of its high double refraction and extinction angle, and it is clearly close to true microcline. This reconstitution of the host K-falspar may be due either to the diffusion into it of Na and Ca from the "vein" perthite lamellae, or to a rearrangement of the monoclinic orthoclase lattice, induced by the adjacent oligoclase-albite of the perthitic "veins." Spencer (1938, p. 107) has recorded a similar effect in microcline, in which the coarseness of the cross-hatch twinning is regulated by the adjacent "vein" perthite.

Slide [5694] is also interesting because there is a change in the nature of the perthite lamellae in the core of the crystal. The "veins" in the outer layers are polysynthetically twinned oligoclase (Ab. 85), but in the core these grade into untwinned bands of lower double refraction (but still higher than the host), which are monoclinic (fig. 4A, B). In the centre of the core the felspar is "shadow" perthite, of mottled appearance under high magnification. Inclusions of quartz follow the boundary of the core, along which there is also a narrow zone of microcline-like felspar resembling that marginal to the "vein" perthite lamellae.

Slide [5693] is a small perthite phenocryst from Loc. M.1. In preparing the slide, the (010) face was polished without removing much of the felspar, and thus the section shows the nature of the outer coating of the crystal. The major portion is soda-orthoclase, with X ∧ (001), 9°, but the margin consists of two distinct zones, an inner composed of coalesced prismatic crystals in which the extinction angle on the trace of the (001) cleavage is 0°, and an outer of soda-orthoclase in optical continuity with the core. The inner of the two zones grades rapidly by means of composition-zoning into the soda-orthoclase on either side without any definite line of demarcation, and has a distinctly higher double refraction and refractive index. The optical properties therefore suggest that the inner of the two border zones is oligoclase. In its anhedral form, the phenocryst differs from true Rapakiwi, but similar oligoclase margins to potash felspar have been recorded from many localities. The present example is unusual, however, in that the oligoclase is followed by a final orthoclase zone. Apart from the microcline fringing "vein" perthite stringers in orthoclase, this mineral is rare in the district. A few crystals showing uniform cross-hatching occur in slides [5708] and [5719].

Plagioclase in the porphyritic granites is typically oligoclase, ranging in composition from Ab. 70 to Ab. 85. The mineral invariably shows composition zoning, frequently with a marked discontinuity between the core and the outer zones ("jacketed" felspar), the latter also frequently containing myrmekite pustules. The plagioclase in the "vein" perthite lamellae averages about Ab. 85 in composition.

Quartz is hypidiomorphic to anhedral, and is present in large amount in all the rocks examined. It is included in the perthite phenocrysts, often along definite growth zones. These inclusions in slide [5693] are unusually large.

Biotite is pleochroic from X pale yellow or yellow-brown to Y, Z dark brown. The crystals frequently show dactylitic terminations against felspars (both orthoclase and oligoclase), and contain many minute inclusions of zircon and apatite, around which pleochroic haloes are developed. It is rarely altered to chlorite, and shows various stages of bleaching, tending towards colourless hydromica.

Muscovite occurs as well-developed plates, and also as stringers replacing orthoclase or microcline. In places it is intergrown in a lamellar arrangement with biotite. The freedom of this muscovite from inclusions of rutile or sphene distinguishes it from bleached biotite. In the Pyramid Hill Quarry, muscovite-quartz replacements of perthite are especially notable [5719].

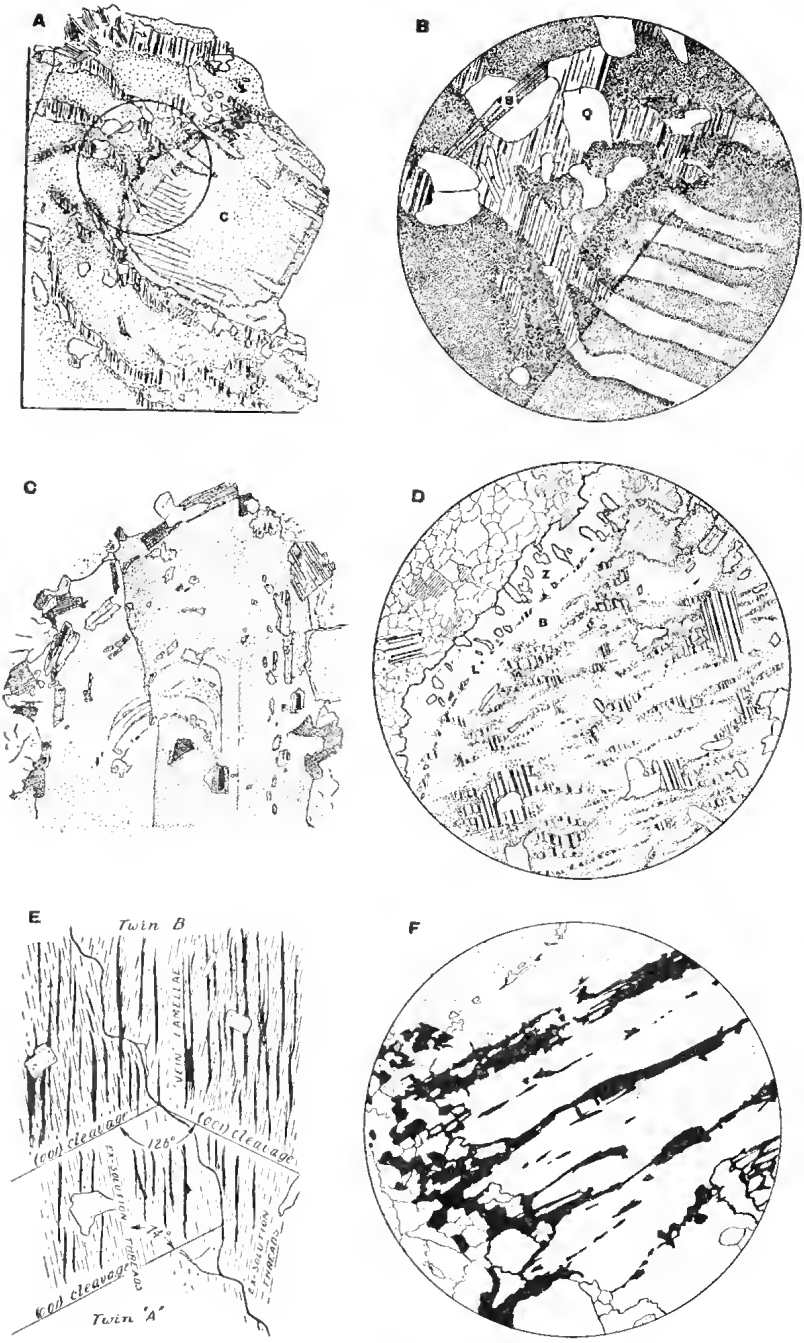

FIG. 4.

FIG. 4.—Types of Micro-Perthitic Structures:—

A.—Portion of a perthite phenocryst from the porphyritic granite, Old Quarry Pyramid Hill [5694] X12. Showing the core C, without perthitic lamellae in the centre, but with untwinned lamellae around the margins, these grading into twinned plagioclase (Ab. 85) in the surrounding potash-felspar.

B.—Enlargement of the portion within the circle in A. X36. In both A and B note the change in the nature of the host-felspar along the twinned perthitic lamellae, as shown by the close stippling. *q*, quartz; *b*, biotite.

C.—Perthite phenocryst in porphyritic granite, Mitiamo. Loc. M4, [5708] X4 Showing composition zoning, and the arrangement of included crystals of quartz, plagioclase, and biotite along growth surfaces, parallel to the composition zones. Note also the tendency for the groundmass crystals, marginal to the phenocryst, to align themselves with long axes parallel to the surface of the perthite phenocryst. Only half the phenocryst is represented in the sketch.

D.—Portion of a perthite in the porphyritic granite, Lake Boga Quarry [5727] X6 Shows a marginal zone *z* containing quartz crystals elongated normal to the potash-felspar crystal face. Beneath this a line of inclusions *i*, of quartz and oligoclase, and beneath this again the body of the phenocryst which is itself bordered with a zone *b* free from perthite lamellae. Note the change in the nature of the host felspar along the plagioclase inclusions as shown by the close stippling.

E.—Perthite phenocryst, Mt. Hope [5690]. Diagrammatic sketch showing the geometrical arrangement of "vein" and ex-solution perthitic inclusions in two halves of a twinned crystal. Section parallel to (010); *c* axis vertical.

F.—Edge of an orthoclase crystal in pegmatitic patch, Old Quarry, Pyramid Hill [5721] X20. Shows replacement of potash-felspar (stippled) by albite (black). Quartz, unshaded.

Accessory minerals present in the granites include apatite, zircon, garnet, ilmenite, and pyrite. The Index Number of porphyritic granite from Pyramid Hill Quarry is 5.61, and from Mt. Hope, 6.25.

2. Even-grained Granite.

Pyramid Hill itself is composed of an even-grained granite which contains abundant muscovite in addition to biotite. A similar type occurs in the old quarry south of the Hill. The granite consists of orthoclase micro-perthite, rare microcline micro-perthite, abundant oligoclase ranging from Ab. 70 to Ab. 85, with biotite and muscovite in sub-equal amounts. Muscovite-quartz associations replace potash-felspar in part. Quartz is abundant, the grains showing sutured interlocking boundaries. Small andalusite prisms are enclosed in the larger muscovite plates [5717, 5718]. Accessory minerals other than andalusite are apatite and zircon. The Index Number is 4.47.

3. Acid Differentiates.

Graphic granite (Loc. H10, slide [5725]) consists of orthoclase-perthite, the intergrown plagioclase consisting of Ab. 70 (oligoclase-andesine). A little muscovite is also present.

Pegmatite occurs as veins and central "combs" in aplite dykes. At Pyramid Hill Quarry, pegmatite veins contain small groups of radiating tourmaline prisms, and consist of orthoclase perthite, oligoclase, muscovite, and quartz [5721].

Aplite dykes are common in both the porphyritic and even-grained granites. Slide [5714] from Mitiamo (Loc. M.3) illustrates the true aplitic types, consisting of quartz, abundant orthoclase-perthite and microcline-perthite, oligoclase (Ab. 80–Ab. 90), very abundant large myrmekite pustules, muscovite, both replacing potash-felspar and as large primary plates, and rare brown or bleached biotite.

Slide [5709] from Mitiamo (Loc. M1) is a rock which in hand specimen appears to be a true aplite, consisting of a fine-grained saccharoidal mass of quartz, felspar, and muscovite. Under the microscope it is seen to contain oligoclase (Ab. 75–Ab. 80), sub-equal to subordinate amounts of orthoclase micro-perthite, rare microcline micro-perthite and abundant quartz and muscovite. The amount of oligoclase present is unusually large, but all the aplitic types sectioned contain larger amounts of this mineral than is usual in granite aplites.

Slide [5715] is an aplitic type that intrudes the even-grained granite of Pyramid Hill. It contains orthoclase-perthite, subordinate oligoclase, a little biotite in large and small flakes, some bleached biotite, muscovite, and andalusite. Coarse patches a few square centimetres across consist of quartz, large muscovite plates, and andalusite.

Porphyry Dykes: A fine-grained dyke at Loc. P8 (slide [5726]) contains small phenocrysts of quartz, felspar, and biotite, averaging about $\frac{1}{4}$ cm. across. Zoned ("jacketed") oligoclase (Ab. 70–Ab. 85) is the dominant felspar, and orthoclase-perthite is subordinate. The other constituents are quartz, biotite (some bleached), and subordinate muscovite. The rock is a quartz porphyrite.

A similar porphyry dyke at Mitiamo (Loc. M1, slide [5713]) contains more orthoclase-perthite, together with some microcline-perthite, though oligoclase is present in sub-equal amounts to potash-felspar. Biotite and muscovite are both present, the latter both replacing potash-felspar and in large primary crystals. This dyke is also a quartz porphyrite.

The largest dyke observed is at Mitiamo, Loc. (M3, slide [5695]). It is about 10 feet wide, strikes at 35°, and is crowded with quartz and felspar phenocrysts averaging about 5 mm. in diameter. In places the felspars are subordinate, and the rock consists of quartz phenocrysts with very little groundmass. The felspars are all completely altered to fine-grained aggregates of limonite-stained sericite, and their original nature is not determinable. The groundmass consists of quartz, sericitised felspars, and partially or completely bleached biotite. The rock is a sericitised quartz porphyry. It carries narrow quartz veins that have been prospected for gold.

4. Melanocratic Schlieren.

The biotite-rich schlieren at Loc. P8, slide [5706], and at Pyramid Hill Quarry, slide [5720], contain large plates of biotite, many being joined together at their ends, where they interdigitate without leaving interstices. Large stout apatite prisms up to 0.5 mm. long are associated with the biotite. The other constituents are orthoclase micro-perthite, oligoclase (Ab. 70), quartz, and subordinate muscovite. Myrmekite is developed in the oligoclase jackets; accessory minerals include apatite in stout prisms up to 0.5 mm. long, also a little apatite in the form of small needles, and zircon.

Slide [5704], from Loc. P7, is fine-grained, but contains a few porphyroblasts of biotite, quartz, and felspar. It shows no banding. Biotite occurs in the manner characteristic of reconstituted xenoliths, as scattered crystals distributed evenly throughout the rock. Many of the biotite flakes are smaller than in slide [5703], and some adjacent small flakes are in parallel orientation, enclosed within a quartz unit. The quartz occurs as plates, full of inclusions of other minerals, the different parts of which are in optical continuity, as described by Brammall (1932) in xenoliths from the Dartmoor granite. In some of these quartz units the included plagioclase and biotite show a radial arrangement, tending towards spherulitic texture. The boundaries

of the quartz plates in places assume a regular geometrical arrangement simulating micrographic intergrowths. One biotite porphyroblast exhibits a large central homogeneous crystal surrounded by a solid mass of irregularly arranged decussate biotite flakes (Baker, 1936, p. 139). The felspar porphyroblasts are oligoclase (Ab. 75–Ab. 85), and the cores of some of the smaller plagioclase crystals are andesine, with jackets of oligoclase grading to (Ab. 85). No potash felspar is present. Apatite occurs as rare stout prisms associated with large biotite clots, and also as numerous needle-shaped inclusions in quartz and plagioclase.

Slide [5705] from Loc. P8 is mineralogically similar to [5704], but the texture of the rock is different. The quartz hosts in which inclusions occur are more compact, containing a smaller proportion of included grains. The felspars are larger, and are also poikilitic. They consist of andesine (Ab. 65) jacketed with oligoclase ranging up to Ab. 85. Potash felspar is absent. (Note: The perthite on the edge of this slide is part of the adjacent granite.) The other constituents are a little muscovite, apatite in the form of long needles (rarely stout prisms), and zircon.

Slide [5707], from Pyramid Hill Quarry, is also similar in a general way to [5704], but the quartz poikiliths assume a pseudomicrographic arrangement, with regular geometrical boundaries to the sieve-like crystals. Quartz intergrowths with oligoclase also assume a form resembling coarse myrmekite, as described by Braunmall (1932). Biotite develops as plates or fringing aggregates surrounding ilmenite grains, and is specially poikilitic, containing numerous inclusions of quartz in optical continuity among themselves. The felspar is oligoclase-andesine, no potash-felspar being present. Large apatite prisms, up to 0.5 mm. long, as well as numerous thin apatite needles, occur.

The Lake Boga Granite.

In the Lake Boga Quarry, which is the only locality where the local granite may be studied in the field, jointing is well developed. One set strikes at 100° and dips at 85° to the north. The complementary approximately vertical joints strike at 190°, and flat-lying joints are also present. All the joints are mineralised, narrow pegmatite selvedges containing black tourmaline crystals up to 8 inches long being developed along them. The granite itself is very heterogeneous. The average is a giant granite porphyry containing phenocrysts of microperthite of a flesh-pink to greenish tinge and about 1½ inch long, together with phenocrysts of muscovite, biotite, and quartz, the largest of these being about ¾ inch across. These crystals are set in a finer-grained granular base composed of the same minerals. Leucocratic patches up to 3 or 4 feet long are free from the large perthite, quartz and mica phenocrysts, but contain patches, veins, and vughs

of tourmaline pegmatite, consisting of quartz, perthite, muscovite, and black tourmaline. The distribution of phenocrysts also varies within the giant granite, lenticular patches being crowded with phenocrysts, while others are even-grained. The latter are darker than the pegmatite-bearing leucocratic varieties. On one face of a few square yards, the giant granite contains numerous xenolith-like blebs up to 6 inches across with hazy borders, and numerous phenocrysts of quartz and felspar. Granite has also been obtained from the Lake Boga Prospecting Company's Bore, at a depth of 200 feet. This is a coarse-textured grey rock containing a considerable amount of biotite, together with quartz and micro-perthite crystals, the latter ranging up to over half an inch in diameter. The available specimens are not large enough to afford an adequate sample of the granite.

The Porphyritic Granite.

This contains large micro-perthite phenocrysts, individual crystals consisting both of monoclinic orthoclase hosts, and triclinic hosts with incipient cross-hatching, developed, as above described, along "vein" perthite lamellae. The latter consist of acid oligoclase (Ab. 80–Ab. 85). Along one edge of the large phenocryst in slide [5727] there is a zone of orthoclase free from "vein" perthite lamellae. This zone is followed by a narrow band along which minute quartz and acid oligoclase crystals are included, and this in turn by an outer zone of orthoclase free from "veins," but including small quartz crystals, most of which are elongated along the *c* axis and lie at right angles to the orthoclase boundary. In the interior parts of the perthite, the "vein" lamellae are arranged in a zonal way, the outlines of the zones being parallel to the crystal boundaries, and evidently related to growth stages. Oligoclase (Ab. 70 Ab. 80), quartz, muscovite, and yellow to red-brown biotite occur as phenocrysts, and the groundmass, which is fine grained, contains perthite, oligoclase, quartz, biotite (some bleached to colourless hydromica, in various stages) and muscovite. Muscovite and biotite are in places intergrown, and minor amounts of muscovite also replace potash felspar. Heavy accessory minerals are rare, apart from tourmaline. There is a little apatite and zircon.

Slide 2043 (Geological Survey Collection) is essentially similar, but is interesting in that the outer acid jacket of oligoclase crystals (Ab. 85) included in perthite is optically and morphologically continuous with the plagioclase of the "vein" lamellae.

Grey Leucocratic lenticles with Pegmatite. The leucocratic base in which the pegmatite vughs and veins are dispersed is a medium-grained, granitic-textured rock consisting of quartz, orthoclase, microcline (with indistinct cross-hatching), abundant plagioclase (andesine Ab. 65 to oligoclase Ab. 80), and muscovite. Biotite is absent, and the potash felspar is free from perthitic lemellae.

both of the "vein" and ex-solution types [5697, 5698]. The felspars are cloudy with alteration products, the potash felspar being more altered than the plagioclase. The chief alteration is kaolinisation, but there is also some development of opacity due to finely-divided limonite. The latter may represent a weathering product of hematite introduced during denteric alteration, and the kaolinisation is also most probably deuteric. The Index Number is 6.25, being identical with that of the Mt. Hope granite.

The pegmatites are not particularly coarse-grained, the crystals averaging about half an inch to one inch in size. They consist of smoky quartz, muscovite, cream perthitic orthoclase grading to microcline, rare apatite crystals as large as the other constituents, and, in patches, black or translucent tourmaline up to 8 inches long.

Pink Lenticular Patches: These are distinguished from the giant granite by absence of perthite phenocrysts, and from the leucocratic grey lenticles by the absence of pegmatite vughs and veins, and by their colour. They are similar to the leucocratic patches in mineral content, except that they contain a large amount of colourless to pale brown and dark brown tourmaline, in the form of skeletal crystals. They also contain a little biotite intergrown with muscovite, and a few anhedral grains of apatite, up to 0.5 mm. across. The larger quartz grains show evidence of regrowth along their margins, and the felspars are again kaolinised and limonite-stained, the potash felspar, as in the leucocratic lenticles, being more strongly altered than the plagioclase [5694, 5700]. The Index Number is 10.14, being abnormally high owing to the presence of tourmaline in large amounts.

The dark xenolith-like patches a few inches across, which occur in the giant granite, are actually tourmaline-bearing clots, similar to the pink lenticular patches except that they contain much more tourmaline, and also carry phenocrysts of quartz, perthite, and plagioclase, like the giant granite.

The granite from the Lake Boga Prospecting Company's bore contains quartz, zoned oligoclase ranging from (Ab. 78 to Ab. 87), perthite, biotite, and muscovite. Slide 2182 (Geological Survey Collection) also contains a biotite-rich clot which is probably of xenolithic origin. It is a biotite-muscovite granite.

Petrogenesis.

Notable features of the above-described rocks are:—(1) the occurrence of two-mica granites, (2) the occurrence of porphyritic granites, and (3) the presence of andalusite in granite and aplite at Pyramid Hill.

The andalusite-bearing rocks are especially interesting in view of the great rarity of xenoliths or other evidences of contamination throughout the province, and have already been discussed by

the author in a previous communication (Hills, 1938). The presence of apatite in pegmatites at the Lake Boga Quarry is also noteworthy, although the amount present is insignificant from the point of view of economic potentialities.

1. *Perthite.*—Ex-solution perthite, and the coarser sub-parallel or ramifying lamellae of the "vein" type appear to grade into each other in many of the slides examined, but the "vein" lamellae are markedly coarser than the very fine ex-solution threads. It has been suggested by E. Spencer (1938) that "vein" perthite is formed by the simultaneous crystallization of plagioclase and the potash felspar host. The hypothesis relates specifically to the microline micro-perthites examined by Spencer, but should presumably be applicable also to orthoclase micro-perthites such as those in the suite here considered. It would be expected, on this hypothesis, that the "vein" plagioclase in the interior of a large potash-felspar crystal would be more calcic than that nearer the periphery, and a more or less regular composition-zoning of the veins might also be developed during crystallization. Such a condition is certainly not typical of the micro-perthites in the rocks here described, although in one example (fig. 4 A, B [5694]) the veins in the core are untwinned and may be composed of a potash-soda-lime felspar rich in potash and soda, while in the outer parts they are twinned oligoclase (Ab. 85). This unusual arrangement is, however, also explicable as due to the unmixing of an original potash-soda-lime felspar which itself had a central core differing in composition from the outer layers.

On the assumption that the plagioclase "veins" are actual injections into or replacements of shattered potash felspar, one would have expected to find inclusions such as quartz and oligoclase traversed by the vein plagioclase, in at least a few examples. This does not occur. Vein injection or replacement, too, would not be likely to give rise to the regular distribution of perthite lamellae throughout large crystals, that is actually observed. It is worthy of note, too, that many albitic replacements of potash felspars in pegmatites show no resemblance to typical perthitic lamellae (see fig. 4 F; also Derry, 1931; Niggli, 1929, figs. 4 and 5). It is therefore suggested that both the "vein" and ex-solution perthitic inclusions resulted from the unmixing of an original potash-soda-lime felspathic solid solution.

2. *Late-Magmatic Phases.*—In both the Terricks Range and Lake Boga granites, differentiation has yielded late-magmatic fractions relatively rich in oligoclase, such as the porphyries and aplites of the Terricks Range, and the leucocratic patches in the Lake Boga granite. The mineral constitution of these aplitic differentiates closely resembles that of the ground-mass of the porphyritic granites. The suggestion is, therefore, that the final magmatic fluid remaining after almost complete solidification of

the potash-felspar-rich granites was relatively enriched in plagioclase (oligoclase). If these differentiates were expressed from the crystal mesh, they produced aplites. The inclusion of small oligoclase crystals along growth lines in the perthite phenocrysts, though not decisive, also suggests that at certain stages the crystallization of potash felspar was retarded, while acid plagioclase was concentrated within the sphere of influence of each perthite phenocryst, until the magma became saturated and oligoclase crystallized.

The pegmatites, on the other hand, contain high-temperature potash felspars in large amount. They are of the type termed "simple pegmatites" by Schaller, in which no extensive replacement of original minerals has gone on, and their formation is readily explicable on the basis of the principles established by Niggli (1929, pp. 2-5).

3. *Jointing.*—All three joint sets in the porphyritic granites—the approximately vertical east-west and north-south joints, and the flat-lying joints—are locally filled with aplitic or pegmatitic veins, and are therefore primary.

4. *Age Relationships.*—Field relationships indicate that the non-porphyritic granite at Pyramid Hill is intrusive into the porphyrtic granite. The profile of Pyramid Hill (see fig. 2, and Hills, 1940, figs. 132, 329), suggests that the even-grained granite is a dyke-like mass, dipping easterly at about 45°, and striking east of north to west of south. It is probable, therefore, although the intervening area is marked by alluvium, that the outcrops at Pyramid Hill and the old quarry are connected along the strike of the dyke.

5. *Petrographic Relationships.*—The minor intrusions of granitic rocks that occur around the fringes of the Murray Basin Plains in north-western Victoria exhibit certain petrographic peculiarities that indicate the existence of a minor petrographic province in this region, perhaps distinct from the Devono-Carboniferous intrusions in the Central Highlands. Thus at Mt. Korong near Wedderburne, a porphyritic two-mica granite closely resembling that of the Terricks Range is intruded by a finer-grained non-porphyritic two-mica granite, as is also the case at Pyramid Hill (Mahony 1911). The Wycheproof granite, which occurs as an isolated low hill rising abruptly above alluvial plains, is a course-grained muscovite granite, and the Wooronook intrusion is a coarse-grained two-mica granite. The Buckrabanyule Hills are composed mainly of a complex granodioritic mass showing evidence of considerable contamination, with strong developments of barren quartz veins, tourmaline-quartz veins, and pegmatitic patches. The intrusion near Borung is also granodiorite. It is fine grained, and has a very well-defined grain. Muscovite-bearing granites are rare in Victoria, as elsewhere, and

it is significant that of the few occurrences in the State, five—Lake Boga, the Terricks Range, Wycheproof, Wooronook, and Mt. Korong—should occur in a well-defined arcuate belt on the western and southern borders of the Wimmera. This suggests that the granites of north-western Victoria may belong to a petrographic province distinct from that of the well-known Devono-Carboniferous granitic rocks of the "dacite suite" in the Central and Eastern parts of the State.

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[Proc. Roy. Soc. Victoria, **53** (N.S.), Pt. I., 1941.]

Art. VII.—*Note on a Collection of Fossils from Queenstown, Tasmania.*

By DOROTHY HILL, M.Sc., Ph.D., and A. B. EDWARDS, Ph.D., D.I.C.

[Read 11th July, 1940; issued separately 1st February, 1941.]

In a recently published outline of the geology of the Mount Lyell Mining Field, Tasmania (Edwards, 1939), the sediments of the Queen River Series, which forms the most westerly of the "four, more or less parallel, north-south trending tracts" of rocks in that district, were considered to be of Upper Silurian age. This conclusion was based upon the determination of fossils found at two localities, namely, (i) some poorly preserved brachiopod casts in what appeared to be an erratic block of the Queen River Series, in the bed of Linda Creek, at the road bridge a little upstream from its confluence with the King River; and (ii) some corals from the limestone in the old flux quarry on the west side of the Strahan road, west of the smelters. Mr. R. B. Withers, who examined the specimens, named a number of the fossils, and expressed the opinion that they indicated for the Queen River Series "an age comparable with the Yeringian Series of the Silurian in Victoria." He suggested, however, that the corals from the old flux quarry should be submitted to Dr. Dorothy Hill for more expert determination.

This was done, and Dr. Hill's identifications, which follow, are such as to place the Queen River Series in the Upper Ordovician or the Lower Silurian, rather than in the Upper Silurian. This change in determination and in age relation applies only to the fossils from the limestone quarry. As the sequel will show, there is every reason to believe that the determination of the brachiopod casts as Yeringian forms is correct.

Significance of the Discovery.

The conglomerates of the West Coast Range are generally accepted as representing the base of the Silurian in Tasmania, and so long as the Queen River Series is regarded as younger than them, it is necessary to postulate that the West Coast Range Conglomerates were raised to their present position relative to the Queen River Series by a great fault of Palaeozoic age, and that the igneous rocks forming the porphyry-schist belt of the Mount Lyell field were intruded along this fault zone. On this view the western scarp of the West Coast Range is to be regarded as an exhumed fault-line scarp. This still holds even if the Queen River Series is regarded as Lower Silurian.

If, however, the Queen River Series is of Upper Ordovician age, it is no longer necessary to postulate such a fault, and the West Coast Range Conglomerates have not necessarily undergone elevation, although some faulting may have occurred along their margin. The West Coast Range, on this view, is simply a feature of differential erosion, resulting from the highly resistant nature of the conglomerates. The fact that beds containing fossils of Silurian age over-lie the West Coast Range Conglomerates at the north end of Lake Margaret, and that an erratic block containing casts of brachiopods of Upper Silurian age has been found in the Linda Valley, and is probably derived from beds now eroded, but once overlying the conglomerates, does not disturb this new interpretation. It is necessary, however, to revise one's conception of the factor controlling the intrusion of the Queen River Porphyries, and the Mount Lyell Schists derived from them. These must be regarded as having been intruded along an unconformity.

It is unfortunate that, in the present state of stratigraphic knowledge, the precise age of these beds remains uncertain, so that no decision can be reached as to which of the conceptions outlined above is correct.

Description of the Fossils.

The preservation of all the fossils in this collection is poor, and one must remain uncertain of the finer structures; photographic figures of the thin sections used in the study are impossible. *Tetradium tasmaniense* Chapman, previously described from Zeehan, has been particularly affected; the interior has been entirely recrystallized into rhombohedral crystals of calcite, and Mr. E. V. Robinson has determined that the exterior has been replaced by or coated with gypsum and small amounts of associated calcium carbonate.

Age of the Fauna.

The fauna contains *Alveolites* sp., *Protarea* cf. *richmondensis* Foerste, *Acidolites* sp., and *Tetradium tasmaniense* Chapman. *Alveolites* ranges from the Middle Ordovician to the Upper Devonian. *Protarea* is known in America from the Trenton and Richmond formations, in Estland from E to E_2, in Sweden in the *Leptaena* limestone, and in Norway in 5a and 5b. *Acidolites* occurs in the *Leptaena* limestone and the F beds of the Baltic, and in the Valentian of Gotland. *Tetradium* is known from the Chazy to the Richmond in N. America, and from the Craighead limestone (Ordovician) in Scotland. This suggests that the age of the Queenstown limestone is probably Trenton or Richmond in the American succession, and F, 5, and *Leptaena* limestone in the various Baltic successions. The Richmond, all or parts of

F, 5, and the *Leptaena* limestone are placed by some in the Upper Ordovician and by others in the Valentian (Lower Silurian. For references see Jones and Hill, 1940, p. 185).

MADREPORARIA TABULATA.

Genus ALVEOLITES Lamarck.

Alveolites Lamarck, 1801, p. 375; for references, genolectotype, etc., see Lecompte, 1939, p. 17.

Diagnosis.—Massive or branching Tabulata, with corallites essentially compressed, of sub-triangular, semi-lunar, reniform or sometimes sub-rectangular section, opening typically obliquely to the surface, with thin, complete tabulae and large mural pores.

Remarks.—Probably *Paleoalveolites* Okulitch (1935, p. 64, geno-type *Tetradium carterense* Bassler) from the Carters limestone (= Black River, = ? Caradoc) is a synonym of this genus, which otherwise extends from the Lower Silurian to the Upper Devonian. Okulitch considered a columella to be present in his genotype, but later (1938, p. 96) placed a second species, without columella, in his genus.

Alveolites sp.

(Plate VII., fig. 1.)

Favosites cf. *grandipora* Eth. fil, Withers *in* Edwards, 1939, p. 69, Queenstown.

Material.—One fragment from the old flux quarry, Queenstown.

Description.—The fragment shows two groups of corallites, one encrusting the other. The transverse section shows semi-lunar or reniform corallites, their average dimensions being 0.5 mm. in the longer diameter, and 0.25 in the shorter diameter; and the corallites run parallel for at least 15 mm., the length of the fragment. Mural pores are very numerous and rather large, and pierce any or all of the walls or angles of the coraflites. Septal spines were not observed with certainty. Tabulae are present, but are distant, thin and concave.

Remarks.—I know of no species with which this might be closely compared. Its corallites are smaller than those of *Paleoalveolites paquettensis* Okulitch (1938, p. 96) from the Black River formation (= Caradoc) of Canada, and it has very numerous mural pores.

MADREPORARIA HELIOLITIDA.

Genus PROTAREA Edwards and Haime.

Protarea Edwards and Haime, 1851, p. 146; Lindstrom, 1899, p. 109.

Genolectotype (chosen Bassler, 1915, p. 1043).—*Porites? vetusta* Hall, 1847, p. 71, pl. xxv., figs. 5*a*, *b*; lower part of the Trenton limestone, near its junction with the Black River limestone, Watertown, Jefferson Co.

DIAGNOSIS.—Lamellar or encrusting Heliolitida without reticulum, with tabularia in which the walls and the twelve septa consist of large trabeculae in contact, and with free trabeculae rising from the floor of the calices.

REMARKS.—According to Foerste (1909, p. 211) and Troedsson (1928, p. 116), the specimens used by Edwards and Haime when they founded *Protarea* on *Porites? vetusta* were not conspecific with the type specimen of *Porites? vetusta* Hall. Foerste described this type as consisting apparently of a succession of lamellae varying from 1 to 2 mm. in thickness, and more or less free from each other in places. There are usually about five corallites in a width of 5 mm., although sometimes the corallites are wider. The vertical tubules between the corallites are fairly distinct under a lens. The calices are rather deep, and the septa scarcely reach half-way to the centre. Foerste, and Troedsson considered that the Baltic and Richmond specimens used by Edwards and Haime and by Lindstrom differed in having no reticulum (i.e. no vertical tubules between the tabularia). For the Richmond forms without reticulum Foerste proposed the name *Protarea richmondensis*. Troedsson considered it probable that the true *vetusta*, thin sections of which have never been figured, was generically different from *P. richmondensis*, and suggested that it might belong to *Protrochiscolithus* Troedsson. Bassler however named *Porites? vetusta* Hall, and not *P. vetusta* of Edwards and Haime quite definitely as genotype of *Protarea*, by giving a bibliographic citation; and it therefore seems that if different generic names are to be used for *vetusta* and *richmondensis*, the new one should be applied to *richmondensis*. Failing figures of thin sections of Hall's holotype of *vetusta*, the genus is here retained with Edwards and Haime's interpretation, i.e., without reticulum. It occurs in the Trenton and Richmond of North America, the *Leptaena* limestone of Sweden, in E, E_1 and E_2 in Estland, and in 5a and 5b in Norway.

PROTAREA RICHMONDENSIS Foerste.

Protarea richmondensis Foerste, 1909, p. 210, pl. iv., fig. 9. Richmond beds of Ohio and Indiana.

DIAGNOSIS.—Encrusting *Protarea* with four corallites in 5 mm., and with the trabeculae in the bottoms of the calices arranged somewhat irregularly.

PROTAREA cf. RICHMONDENSIS Foerste.

(Plate VII., fig. 2.)

Favosites cf. *Gothlandica* Lamarck; Withers in Edwards, 1939, p. 69, Queenstown.

REMARKS ON THE TASMANIAN SPECIMEN.—The Tasmanian specimen agrees very well with Foerste's description, except that there are only three calices in 5 mm. It cannot be ascertained however whether it is encrusting; it is certainly a thin expansion.

In Canada and the U.S.A. the species occurs in Richmond beds; Lindstrom figured as *P. vetusta* a specimen from the Wesenberg beds of Estland. The Tasmanian specimen from Queenstown has its calical surface replaced by gypsum, and part of this is swollen and distorted by subsequent decomposition of the gypsum.

Genus ACIDOLITES Lang, Smith and Thomas.

Acidolites Lang, Smith and Thomas, 1940, p. 13, *nom. nov.* for Jones and Hill, 1940, p. 184.

Acantholithus was preoccupied by Stimpson, 1858, for a crustacean.

GENOTYPE:—*Heliolites asteriscus* Roemer, see Lindstrom, 1899, p. 113, pl. xi., figs. 31-35, glacial drift of Sadewitz.

DIAGNOSIS.—Heliolitida with tubular reticulum, thickened walls, and spines on the tabulae.

REMARKS.—The genus differs from *Heliolites* itself only in the thickening of the walls, which is only less extreme than that in *Coccoseris* Eichwald (1860, genotype *Lophoseris ungerni* Eichwald, Lindstrom, 1899, p. 107, pl. xii., figs. 3-7, F_1 of Baltic), and in the more general occurrence of trabeculae on the tabulae. It may be that *Acidolithus* is better regarded as a synonym of *Coccoseris* but failing re-examination of the types, it seems wise to use *Acidolithus* for the less thickened members, although both genera have the same range in time, viz. Upper Ordovician and Lower Silurian of Europe.

ACANTHOLITHUS sp.

(Plate VII., figs. *3a, b.*)

Cyathophyllum sp. Withers in Edwards, 1939, p. 69, Queenstown.

MATERIAL.—One specimen from the old flux quarry, Queenstown.

DESCRIPTION.—The corallum is 7 mm. thick, entirely surrounding a more or less cylindrical stem of *Tetradium tasmaniense*. On the surface calices about 0.5 mm. wide are 1 to 2 mm. apart, the intervening reticulum appearing minutely and closely papillate. Twelve septa line the calices, which sometimes show axial projections also. In vertical section the reticulum shows trabeculae continuous vertically, as thick as the distance between them, about 0.01 mm., connected by thin sola, the sola between neighbouring trabeculae continuing the same line, so that the whole corallum shows a number of concentric lines; this concentric structure is emphasized by a recurrent colouration of the corallum. The sola are close but the tabuli of the tabularia are very distant and concave. The septa appear to consist of long, upcurved spines, those of each of the twelve vertical series are so close as to form vertical laminae in some of the tabularia. In one case trabeculae were observed based on the upper surface of a tabula. In another tabularium there was a suggestion of a columella.

Remarks.—The trabeculae of the reticulum are probably united to form polygonal tubuli, but no such outlines could be clearly seen in transverse section. The species does not appear to be close to any of the species described by Lindstrom, differing in the smaller size of its calices and in the indistinctness of the outlines of the tubuli, as also in the thinner walls. It resembles very closely the figures given by Lambe (1899, pl. v, figs. 8, 8a) of a specimen from the Trenton (Upper Ordovician) of Ottawa, Ontario, which he referred to *Protarea vetusta* Hall. The age it indicates would be that of the genus, F_1 or F_2 and Lower Valentian of the Baltic, i.e. Upper Ordovician or Lower Silurian.

GENUS INCERTAE SEDIS.

Genus TETRADIUM Safford.

Tetradium Dana, 1846, p. 701. *Nom. nud.*, as no species were named

Tetradium Safford, 1856, p. 236.

Genotype (by designation): *Tetradium fibratum* Safford, 1856, p. 237; Upper Ordovician of Tennessee, associated with *Favistella alveolata* (Goldfuss) and other Hudson River species.

Diagnosis.—Colonies which are hemispherical, lamellar, branching, cateniform or in small bundles, consisting of long prismatic tubes, usually four-sided, a lamina projecting towards the axis from the middle line of each wall; when the laminae meet at the axis the original tube is divided into four. The walls are without pores, but the tubes may be divided transversely.

Remarks.—Dana named no species when he proposed the genus, and so, according to Article 25b of the International Rules of Zoological Nomenclature, his genus is invalid; but he gave a good description, and said it was based on a specimen, whose number was not given, from an unknown locality, in Yale College, New Haven. Safford, the first to use the name with species, applied it to the same general group as Dana, and as he was the first author to use a recognisable genotype, the genus should be ascribed to him.

The genus has usually been included with the corals, and indeed the vertical laminae have somewhat the appearance of the septa of corals. Okulitch has reviewed the literature in which the genus has been placed in the Anthozoa, and has regarded them (1935, p. 72) as forming a separate Proto-anthozoan group, bridging the gap between the Tetracoralla and the Alcyonaria, which he later (1936, p. 378) called the Schizocoralla. The latest Canadian Geological Survey Memoir (202) on the Ordovician of Ontario and Quebec lists *Tetradium* as a Hydrozoan, and this may be right. I do not think the genus shows sufficient resemblances to the Anthozoa to justify placing it in that class. The laminae appear to be connected only with increase, in a similar way to the divisional laminae which grow out from the walls of the Rugose coral Stauria during increase; they do not appear to be

divisible into major and minor cycles like the septa in the Rugosa, nor into successive cycles as in the Hexacoralla; nor are they acanthine as in the Tabulata or the Heliolitida. The Tasmanian specimens are not sufficiently well preserved to throw any light on the microscopic structure of the genus.

Bassler has listed the American species of the genus (1915, p. 1264) and Chapman (1919, p. 8) has given diagnoses. Okulitch (1935) has recently re-described them. They are found in the north-east of the United States, and the east of Canada, in the Stones River (= Chazy), Black R., Trenton, and Richmond groups, i.e., from the Llanvirn to the Ashgill, and possibly into the Lower Silurian. Outside America the genus is recorded in the Ordovician Craighead limestone of Scotland, and our species was originally described from Zeehan in Tasmania.

TETRADIUM TASMANIENSE Chapman.

Tetradium tasmaniense Chapman, 1919, p. 8, pl.; Smelters-road, Zeehan, Tasmania, in a compact, blue-black limestone, the Gordon River limestone. Upper Ordovician or Lower Silurian.

Favosites aff. *Limitaris* Rominger; Withers *in* Edwards, 1939, p. 69. Queenstown.

? Campophyllum sp. Withers in Edwards, 1939, p. 69, Queenstown.

TYPES are in the National Museum, Melbourne.

DIAGNOSIS.—*Tetradium* with branches about 11 mm. in diameter, but occasionally constricted, springing from an irregular base, with tubes four-sided, about 1.5 mm. in diameter, incompletely or completely quartered by vertical laminae springing from the middle of each wall, and with occasional thin tabulae.

REMARKS ON THE QUEENSTOWN SPECIMENS.—The branches are not regularly cylindrical, and vary in diameter from 7 mm. to 11 mm.; their entire surfaces consist of calical openings, about 3 in 4 mm., or 4 in 5 mm. The outline of the calices is frequently that of a four-petalled Tudor rose. The laminae tend to be thicker near the walls, and between them the walls are curved in transverse section. The course of the tubes in the branches is not known. It appears from Chapman's description of the Zeehan specimens that he saw no surfaces of the branch, but only sections of the internal parts of the branch. But from the measurements of both our specimens, and from the transverse section he figures, I think they are the same species. The Tasmanian species somewhat resembles *T. cellulosum* (Hall, 1847, p. 39, pl. ix.) from the Birdseye Limestone of New York, as the latter also is digitate or ramulose. Hall states that its branches anastomose, however, and this condition is not known in the Tasmanian species. Further, from Okulitch's description (1935, p. 54) of *T. cellulosum*, it would appear that the tubes were always parallel to the axis of the branch, and could not have opened on the surface of the branch. But Hall's description seems to allow that they did so open. Okulitch's description may not have been

based on Hall's type specimens. Our species would appear to be a branching modification of the massive *T. fibratum* group, which occurs in the Black River, Trenton, and Richmond of North America. Its age may thus be Middle or Upper Ordovician, or Lower Silurian, if the Richmond be regarded as Lower Silurian, rather than Upper Ordovician.

CEPHALOPODS.

Rhizophyllum sp. Withers *in* Edwards, 1939, p. 69, Queenstown.

These specimens, which are nautiloid cephalopods, are being investigated by Dr. F. W. Whitehouse.

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Explanation to Plate.

Plate VII.

All figures approximately × 1.8 diameters.

All specimens are from the old flux quarry, now disused, at the northern end of Queenstown on the western side of the Strahan road, before it climbs out of the valley of the Queen R., half a mile N. of the railway crossing. They were collected by Dr. A. B. Edwards and are at present in the collection of the University of Queensland. The age of the limestone is Trenton or Richmond; i.e., Upper Ordovician or, if the alternative view of the age of the Richmond be accepted, Lower Silurian.

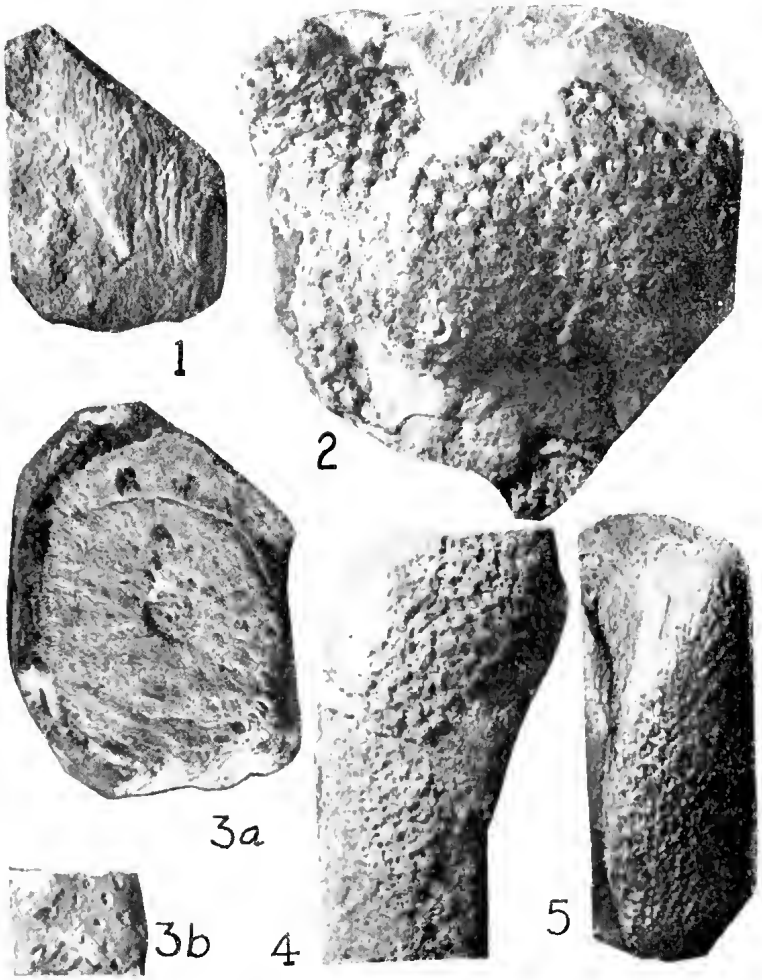
Fig. 1.—*Alveolites* sp. F.4287.

Fig. 2.—*Protarea* cf. *richmondensis* Foerste F.4288.

Fig. 3.—*Acidolites* sp. F.4289.

Fig. 4.—*Tetradium tasmaniense* Chapman F.4290.

Fig. 5.—T. *tasmaniense* F.4291.



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[Proc. Roy. Soc. Victoria, **53** (N.S.), Pt. II., 1941.]

Art. VIII.—*The North-West Coast of Tasmania.*

By A. B. EDWARDS, Ph.D., D.I.C.

[Read 12th September, 1940; issued separately 26th July, 1941.]

Introduction.
The North-West Coastline.
I. Silted Indentations with Prominent Cliffed Headlands:
Badger Head Bay—Port Sorrell and the Rubicon Estuary—Rocky Cape.
II. The Scarp Coast:
Devonport to Jacob's Boat Harbour—Stanley Peninsula.
III. The Emergent Coastline:
Perkin's Bay—Smithton to Woolnorth and Marrawah.
The Raised Shorelines.
Submerged Shorelines.
Origin of the Oscillating Shorelines.
Appendix: Fossil Assemblage, Mt. Cameron West.

Introduction.

Although several short sections of the North-West Coast of Tasmania have been described briefly in various publications of the Geological Survey of Tasmania (Loftus Hills, 1913; Nye, 1934), and the geology of that part of it lying between West Head and Circular Head has been mapped in some detail (Stephens, 1908), no consecutive account of the coastal features has appeared.

The following notes are based upon observations made by the author during a recent visit to North-West Tasmania, when he had occasion to visit the coastline at a number of points between West Head and Marrawah, in connection with a field study of Tasmanian basaltic rocks. The cost of the field-work was defrayed by grants from the University of Melbourne and the Australian and New Zealand Association for the Advancement of Science.

The North-West Coastline.

The north-west coastline of Tasmania is a compound one, and, from the evidence of raised strandlines and submerged valleys, its submergent and emergent features are due largely to the successive eustatic rises and falls of sea-level during the Glacial and Post-Glacial periods. During the periods of low sea-level the river valleys were deepened to below present sea-level, while during the periods of high sea-level estuarine conditions extended much further inland than at present, and gave rise to high level

flood plains, which are now preserved in the river valleys, as paired terraces. No one stage of high or low sea-level was maintained sufficiently long to allow the coastline to mature, so that it is made up of youthful features of submergence combined with youthful features of emergence. East of Devonport features due to submergence tend to dominate, while west of Stanley those due to emergence are the more prominent.

The north-west coastline differs greatly in appearance from that of South-Eastern Tasmania, although the processes involved in their development were identical. This difference is chiefly the result of their different geological structure. In the south-eastern part of the island there is a repeated alternation of narrow belts of relatively non-resistant Trias-Jura and Permo-Carboniferous sediments with narrow belts of highly resistant dolerites, often in the form of dyke-like masses which strike more or less at right angles to the coastline. As a result deep and narrow valleys have been eroded in the confined belts of softer rock, and the dolerite valley walls have tended to keep such streams from combining with one another. Submergence of this region has given rise to a number of long, narrow arms of the sea, separated by steep sided peninsulas that tail off into islands. On account of their original depth, these drowned valleys were not readily silted up.

In the north-west of Tasmania, on the other hand, the rocks offer a much more uniform resistance to erosion over wide areas. Only at widely separated intervals, where very resistant sediments were developed, as in the Asbestos Ranges, the Dial Ranges, and the Dip Ranges, has differential erosion been marked. These ranges form prominent headlands and reaches of rocky coast. In the wide intervening stretches of somewhat less resistant rocks, stream erosion developed wide valley systems, with a trunk river fed by numerous tributaries. Subsequently many of these wide valleys were filled by lava-flows, chiefly basaltic, and completely buried beneath a wide lava-plain. Between West Head and Marrawah (fig. 1) the coastal features are of three general types, each of which is closely related to the geological structures of the region concerned. For convenience these can be referred to as:—

1. Silted Indentations with Prominent Cliffed Headlands.

This type of coastline occurs along the stretch of coast between West Head and Devonport; and between Jacob's Boat Harbour, Rocky Cape and Stanley. It is made up of wide, deep bays, several miles across, which have been cut in belts of relatively resistant sediments (not covered with basalt) bordered by prominent cliffed headlands that have been cut in still more resistant rocks. Bay-mouth bars, and mid-bay bars, have closed off the heads of these bays, and led to their extensive silting up, so that the depths of the original indentations are masked in plans

which do not show the topography of the region. It seems possible that these bars may be as much due to emergence as to beach-drifting.

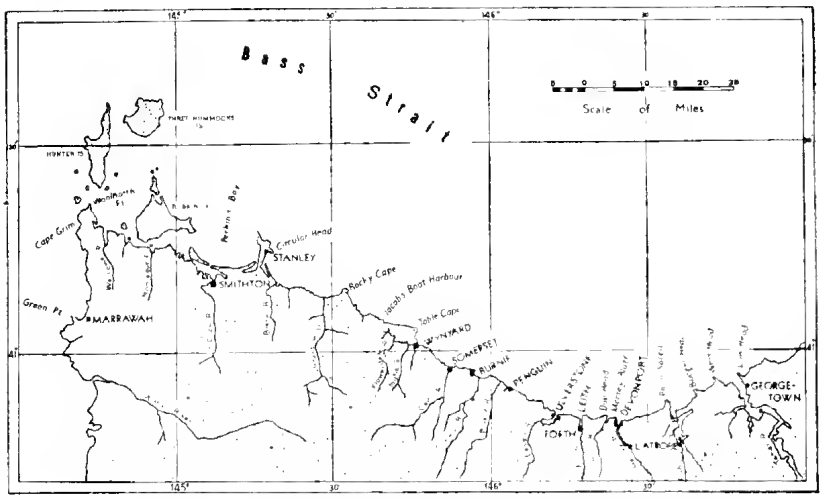

FIG. 1.—Locality Map of the North-West Coast of Tasmania.

2. THE SCARP COAST.

This extends from Devonport, through Ulverstone, Burnie, Wynyard and Table Cape, as far as Jacob's Boat Harbour; and also occurs in the immediate vicinity of Stanley Peninsula and Marrawah.

Its distinctive feature is the occurrence of a narrow emergent coastal plain, backed by a more or less continuous scarp that sometimes exceeds 200 feet in height. It owes its development to the undercutting by marine erosion of the sheet-like flows of basalt covering the Cambro-Ordovician and Permo-Carboniferous rocks which outcrop at present sea-level in these regions. The basalts in-filled the wide and gently sloping valley systems in these sediments, and formed a plain which rises slowly inland (fig. 2A). Marine erosion of this plain has produced a slowly heightening line of cliffs; and subsequent emergence of the old shore platform to the position of a coastal plain has removed the line of cliff from further attack by the sea, leaving it to weather into a steep escarpment (fig. 2B). Where the major rivers, like the Mersey, Leven and Forth come down to the sea, the coastal plain widens and the scarp shows a corresponding embayment.

The lava-flows in-filling the deeper parts of the old valleys frequently extended below present sea-level, and in a number of places still do. Where the width of lava-filled valley passing

below sea-level was not great, marine erosion cut away the valley walls, leaving the basalt-filled valley as a peninsula or narrow headland. Later, however, the encroaching shore platform reached the point where the bottom of the lava-filled valley passed above sea-level. Undercutting followed, and that portion of the lava-filled valley which passed below sea-level was left as an isolated outcrop of basalt on the shore platform (fig. 2B). Where the width of basalt was considerable it remained as an elongated, ridge-like island, such as Stanley Peninsula once was; where the volume of basalt was smaller it became worn down more or less to the level of the shore platform, although it frequently continued to protrude above the platform as rock stacks, like the Doctor's Rocks.

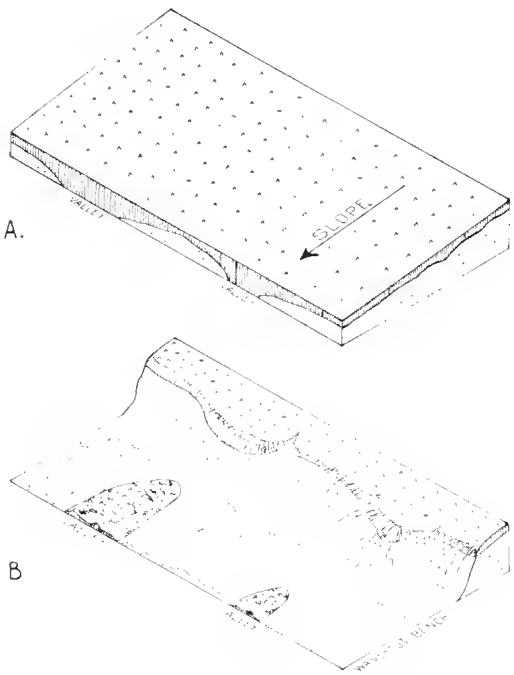

FIG. 2.—Diagram illustrating the formation of the Scarp Coast. A. Basalt plain, before erosion; B. After the formation of a shore platform and subsequent emergence.

Where the width of the lava-filled valley or valleys passing below present sea-level was considerable, as between Table Cape and Jacob's Boat Harbour, or to a lesser degree at Don Heads, the resistant nature of the basalt appears to have restricted the width of such shore platforms as formed prior to the last emergence of the coastal region, and the present phase of marine erosion has removed all but a few traces of them. As a result,

along these stretches of the coast the scarp coincides with the present cliffs, which are 200 to 300 feet high. A narrow wave-cut bench has been formed at the base of the cliffs, and is kept free from debris by wave action, while the lower parts of the cliffs show almost vertical slopes (Pl. IX., fig. 3).

3. The "Emergent" Coast.

This variety of coast extends from west of the Stanley Peninsula as far as Marrawah. It is made up of a deeply indented coastline of the first type, fronted by a wide coastal plain of recent emergence, and extensive swamps. Here and there in this plain are hills of resistant rocks which were previously islands, but have been "resumed" with the emergence of the coastal plain.

I. Silted Indentations with Prominent Cliffed Headlands.

Badger Head Bay: The name Badger Head Bay is used here for the apparently nameless bay between the two prominent headlands of West Head and Badger Head, west of the mouth of the Tamar (fig. 3). West Head is part of a ridge of columnar

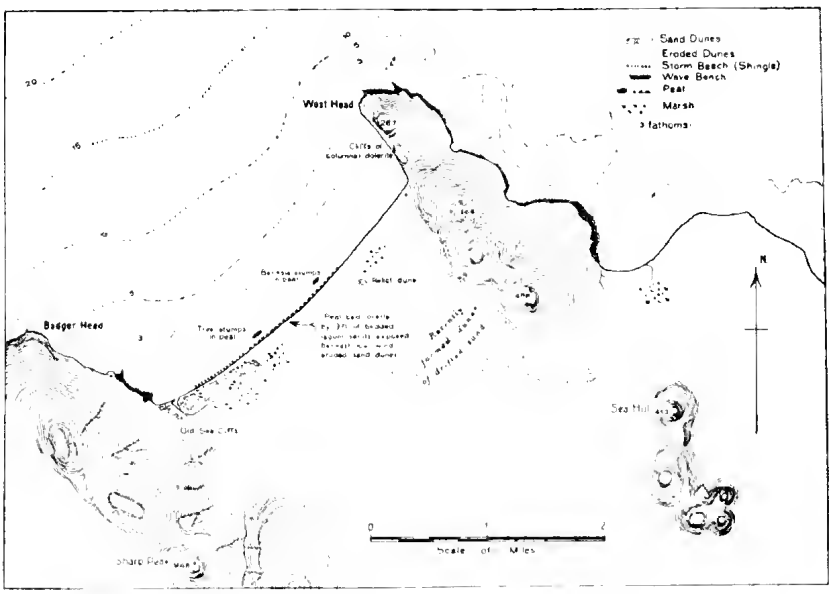

Fig. 3.—Map of Badger Head Bay (adopted from Admiralty Chart No. 3049, Folio 98).

dolerite, which in places forms vertical cliffs over 100 feet high. Badger Head is composed of the overfolded Pre-Cambrian schists and quartzites of the Asbestos Range. Between these two headlands is a beach four miles long, backed by sand dunes. These are protected from north-easterly winds by West Head, but are

only partially protected from strong north-westerly winds by Badger Head. At the western end of the beach the dunes are 20 to 30 feet high, and tree covered. About one-third of the way along the beach, going eastwards, they become exposed to winds blowing past Badger Head, and in a distance of about 100 yards a transition takes place from stationary dunes to dune remnants (Pl. VIII., fig. 6) which do not rise more than 3 to 4 feet above the level of the backshore. An occasional partially eroded high dune remains to show that these wind eroded dunes were once as high as those at the western end of the beach. The remaining dunes form ridges more or less parallel to the general wind direction. The sand from the eroded dunes has been blown inland for a distance of several miles, burying the lagoon that existed behind the old dunes, and also accumulating on the western slope of the dolerite ridge that forms West Head.

A storm beach of coarse shingle has been built up to a height of 4 to 6 feet above the high tide level on the backshore, along its central and western part (Pl. VIII., fig. 4); and this protects the bases of the sand dunes from erosion by storm waves. This storm beach has a steep slope to the sea, and a more gentle slope to the dunes, and the pebbles that compose it lie with their flat faces more or less parallel. In places small impermanent lagoons are enclosed between this ridge and the sand dunes.

Swampy conditions exist behind the dunes at the west end of the bay, and once extended the greater length of the bay, where a bed of peat two or more feet thick is exposed beneath a 3-ft. thickness of bedded, iron-stained sand, in the foot of the low cliff, beneath the dune remnants. The iron-stained sands contain grains of buckshot gravel, and a thin layer of buckshot marks the contact of the bedded sand, deposited in the now-buried lagoon, and the sand of the dunes. This peat is also exposed below the storm beach (Pl. VIII., fig. 3), while at low tide two patches of tree stumps and roots (chiefly *Banksia* (?)) set in peat, each covering an area of about 50 square yards, are exposed near the foot of the beach, about 80 to 100 yards from the cliff-face (Pl. VIII., figs. 1, 2, 5).

This indicates that the present recession of the dunes is part of a long continued process; and that previously there was, across Badger Head Bay, a bay-mouth bar which has now been driven in over the lagoon which it enclosed, to the position of a mid-bay bar. The old sea-cliffs, formed prior to the development of the bar, can be observed behind the present marshy lagoon near the western end of the bay.

Several streams run into the bay, and preserve their courses through the sand dunes, but only that one which drains the lagoon at the west end contains permanent water. Eastward drift of sand has deflected its mouth about 100 yards to the east, along the face of the sand dunes. The mouth is closed by a

bar; and when this bursts, the dunes on the outside curve of the "meander" caused by the deflection of the stream are energetically undercut and form steep cliffs. The storm beach prevents the deflection of the mouths of the streams crossing the sand smothered area. These streams are dry, except after rain.

Port Sorell and the Rubicon Estuary: Port Sorell is at the mouth of the Rubicon and Franklin Estuary (fig. 4), where these rivers empty into the wide bay to the west of Badger Head. The estuary is tidal for about eight miles upstream from this point. Point Sorell, the west headland of the bay, consists of Mesozoic dolerite. From Hawley to Point Sorell the surface of the dolerite forms a narrow, somewhat marshy, coastal plain, fronted by low sand dunes. This tract, which is 20 to 30 feet

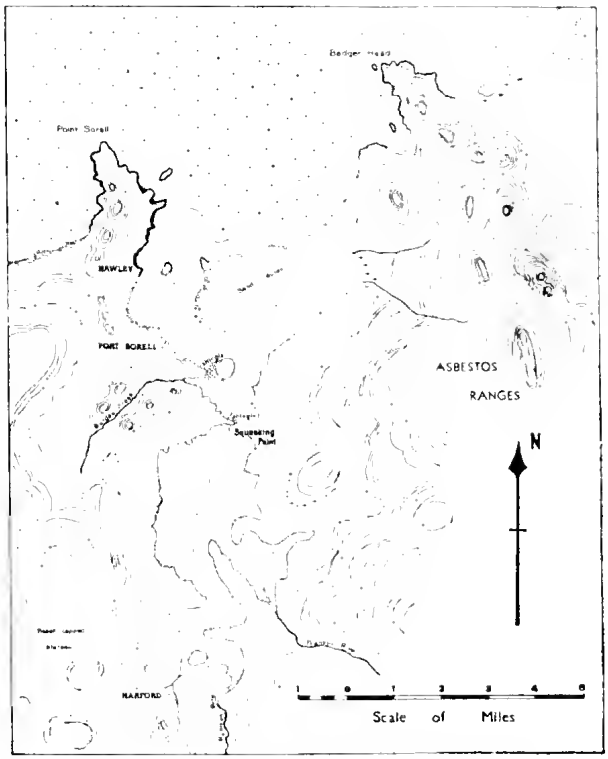

FIG. 4.—Map of Port Sorrell and the Rubicon Estuary (adapted from Admiralty Chart No. 1079, Folio 98).

above the present beach level, appears to be part of an old shore platform. The dolerite extends beneath the mouth of the estuary, and outcrops as a reef on the east side of the channel, and as an island, tied at low tide to the west bank, on the western edge of the channel. The island rises 10 to 15 feet above high water level.

A curving mid-bay bar, five miles long, extends from Badger Head to the eastern limit of the dolerite. The bar is about a mile wide, and is capped by sand dunes 30 to 40 feet high. Behind the bar extends an arm of the estuary, over three miles long, and from three-quarters of a mile to one mile wide, which provides some indication of the original depth of the bay. The growth of the bar has forced the estuary mouth over to the western side of the bay, where it has cut a channel through the dolerite, probably with the help of tidal scour.

Half a mile upstream from the Port Sorell jetty, there is a small island, rising a few feet above high tide level, and tied to the west bank at low water. The bed of the estuary here is composed of a light shingle of marine origin. The pebbles are of quartzite, and are apparently derived from the Asbestos Range. The island is built upon beds of this shingle that rise one to two feet above high water level. Presumably the shingle marks the position of a sea-beach formed before the mid-bay bar closed the bay. It may be an old beach ridge, or the fact that it occurs above high water may indicate slight uplift.

Two miles further upstream, at Squeaking Point, similar shingle is found, forming a flat bank about 10 feet above high water. Here, presumably, we have evidence of an emergence of this order. The shingle continues upstream for some distance. Going inland from Squeaking Point (westwards) a terrace 25 to 30 feet above the estuary level is encountered in a distance of about 100 yards. The upper surface of this terrace is sandy, and somewhat uneven. It continues inland until near Burges Creek, where there is a change to hilly country.

Five miles further upstream, where the State Highway from Devonport to Exeter crosses the Rubicon River, near Harford, the river, which is still tidal, has cut down to a depth of about 30 feet through an old flood plain which forms well marked high-level flats on either side of the estuary, and also on an island in midstream—left where a tributary joins the Rubicon a short distance downstream from the road bridge. This old flood plain appears to be contiguous with the higher terrace at Squeaking Point. Upstream from the Harford Bridge the river is incising a meander in the raised flood plain. This terracing may be taken as evidence of a repeated emergence of the coastal region of the orders of 10 and 30 feet.

Rocky Cape: West of Jacob's Boat Harbour the coast is formed of a belt of Pre-Cambrian quartzites, about seven miles wide. These rocks are highly resistant, and stand in relief as the Dip Ranges. Prior to the basalt extrusions these ranges formed a much more prominent divide than they do now, and they are still conspicuous. Along the seven miles of coastline to Rocky Cape the cliffs rise steeply from the water's edge, except

near the mouth of Sisters Creek, where there is a belt of low sand dunes and quartz gravels, fronted by beach. A small island, Sisters Island, occurs off the coast at this point.

Rocky Cape itself is formed of particularly hard white quartzites which are strongly bedded and dip at about 45 degrees to the north. Prominent vertical joints cut across the bedding. In profile Rocky Cape consists of a series of blocks showing dip slopes to the north and steep scarp to the south (Pl. IX., fig. 2). Stephens (1908) considers that the scarps are due to faulting, but they may have developed from erosion of strongly jointed zones.

Two sea-caves at heights of 50 to 60 feet above sea-level occur at Rocky Cape. These caves, which have been described by Stephens (1908) are cut in cliffs of white quartzite. The strong bedding planes and intersecting vertical joints have defined the shape of the caves. The northernmost cave (Pl. IX., fig. 1) occurs in a cliff about 160 feet high. The cave is about 40 feet high at the entrance and 15 feet wide. It runs back into the cliff face for about 25 yards, the floor sloping gently upwards, and the roof coming down, while the cave narrows to about 3 feet wide. It appears to be about 60 feet above present sea-level, but this is somewhat misleading, because the floor is covered with a midden-deposit that is more than 10 feet thick. The cave opens to the west, and its portal faces the remnant of an old shore platform. Examination of this platform reveals sea-worn pebbles on its surface. These are readily distinguished from the markedly angular hill-wash of this region.

A second cave, facing towards Table Cape, occurs half a mile to the south of the first. It is of similar construction, except that the back of the cave is narrower, and the walls on either side are bedding plains dipping north. This cave is filled to a much greater depth with midden deposit in and about the entrance, so that it appears to stand 70 or 80 feet above sea-level, with a portal only 10 feet high. On going into the back of the cave about 50 feet, however, one descends nearly 20 feet in the sloping cleft, even though the floor is still covered with midden deposit. It follows that the cave floor cannot be more than about 50 feet above sea-level, and that its dimensions are of the order of those of the more northerly cave. Remnants of an old wave-cut bench at about the same level as the probable floor level of the cave form ridges that jut out for about 100 feet on either side of it, before descending abruptly to the sea. Cliffs, contiguous with the cliff in which the cave is cut, mark their landward terminations.

West of Rocky Cape there is a wide deep bay, whose further headland was formed by the ridges of Cambro-Ordovician sediments west of the Detention River. This bay has been silted up, with the formation of a marshy lagoon behind the sand dunes

of the bar. The dunes form a series of ridges varying in number from four to seven, parallel to the coastline. The ridges show gentle slopes to seaward, and steep slopes towards the marsh. Cliffs are being cut in the outermost dunes, exposing the roots of the trees along their crests, but there is no indication of a peat layer on the seaward side of the dunes, which appear to rest on a rock bench, and the fact that a patch of basalt, covered by a veneer of shingle occurs midway between the mouth of the Detention River and the road bridge, suggests that much of the marsh is underlain by a shore platform, at no great depth. Where the road bridge crosses the Detention River there is a depth of water of about 10 feet, due to the damming of the river by a sand-bar. The water surface is still 15 to 20 feet below the level of the sand ridges on either side however.

From Detention River to Black River the coastal features consist of old cliffs fronted by narrow strips of raised shore platform, or marshes fronted by sand-dunes, and irregular wave-cut benches of Cambro-Ordovician sediments interspersed with stretches of sandy beach. Black River, which is tidal for some distance upstream, has cut down to a depth of about 30 feet below the level of the flat sandy plain behind the lagoons at its mouth. This plain, which is 54 feet above sea-level at Black River railway station, appears to be a raised beach, elevated prior to the formation of the sand-bar which encloses the lagoons.

II. The Scarp Coast.

Devonport to Jacob's Boat Harbour: Between Point Sorell and Devonport a change in the nature of the coast is caused by the changed geology—the basalt plains which extend inland from the coast. Near Devonport, at the western end of Pardoe's Beach, the coast consists of a narrow coastal plain, formed by the emergence of a shore platform, backed by a scarp that is capped by basalt lava-flows; and these features continue almost without a break as far as Jacob's Boat Harbour.

The width of the coastal plain varies somewhat, widening to a mile or more on either side of the mouths of rivers like the Mersey, Leven, Forth, Emu and Inglis, and narrowing to as little as a hundred yards, or even less, in the intervening stretches. The line of the scarp is, therefore, sinuous. Where the coastal plain widens it is usually fronted by lines of sand dunes and storm beaches of shingle, and behind these barriers lagoons (usually drained) have developed to various extents. Where the plain narrows, the line of sand dunes may or may not continue, but generally the rocks forming the present wave-cut bench are exposed, either as a continuous bench backed by low cliffs cut in the raised platform, or as a discontinuous wave-cut bench, forming a series of small headlands separating strips of sandy beach. Along much of this coastline the rocks in which the

waves are working are much-folded Cambro-Ordovician strata of varying hardness, and the wave-cut benches developed in these rocks are correspondingly irregular in shape and surface. Where, however, the bench is cut in softer Permo-Carboniferous sediments, as between Wynyard and Seabrook, the bench is a much more even surface, and only protrudes at low tide.

At the present cliff-line the coastal plain is 20 to 25 feet above sea-level. It rises gently inland, and is about 40 to 50 feet above sea-level near the foot of the scarp, which marks the old cliff line. Frequently the actual height at the foot of the scarp is more than 50 feet above sea-level, as a result of accumulation of hill-wash material.

Old rock stacks stand up above the general level of the plain at a number of points, as at Doctor's Rocks, and Woody Hill, between Burnie and Wynyard, and at Goat Island, near Ulverstone. Raised beaches of rounded boulders and coarse shingle form a veneer on the raised platform at the first two of these points, and a pebble beach is exposed at Sulphur Creek. More extensive raised beaches, which merge into flood plains, are found at the mouths of nearly all the rivers entering the sea along this stretch of coast; and most of the coastal townships are built upon these deposits.

Mersey River: The banks of the Mersey at Devonport rise to a height of 20 to 40 feet above the high-water level of the estuary, and are built partly of beach deposits and partly of silt. Upstream, as noted by Twelvetrees (1911), the Mersey valley contains well developed terraces 20 to 30 feet above the present flood plain, and these extend from Devonport to beyond Latrobe, a distance of more than four miles. Twelvetrees suggests that the region has been affected by repeated uplift because he observed traces of what he considered were still earlier flood plains in the Mersey valley.

At the western end of Devonport township is the small promontory of Mersey Bluff, which at some time may have formed the western headland of a deep bay now occupied by the coastal plain and estuary of the Mersey. This promontory is composed of Mesozoic dolerite, and formed part of a ridge separating two parallel valleys, now marked by basalt flows which pass below sea-level on either side of the Bluff. The Bluff was an island during the high sea-level periods, and now presents the appearance of a small tied island, but the sand dunes on the western side of the tombolo may mask a connection with a raised shore platform that runs from west of the Bluff to the mouth of the Don River.

The basalt on the eastern side of the Bluff is largely covered by beds of shingle to a height of about 20 feet above high water mark (Stephens, 1908). That on the western side forms the eastern headland of the Don Estuary, where it is covered with

beach ridges of coarse basalt shingle. On the western side of the small estuary it forms the Don Heads, which is a line of cliffs, composed of more than one flow of basalt, marking the position of a deep, wide valley that passed well below present sea-level. Along this stretch of the coast the coastal plain is lacking, and the scarp coincides with the cliff-line. West of this basalt-filled valley the scarp recedes, and a narrow coastal plain develops again, and continues as far as Leith. A smaller basalt-filled valley passes below sea-level at the eastern end of Lillico's Beach, but the basalt residual is no longer connected to the basalt on top of the scarp.

Forth River: Paired terraces, about 30 feet above the level of the present flood plain of the river, extend for a distance of about nine miles up the Forth River from the township of Forth; and just below the bridge at Paloona is what appears to be a remnant of a second set of terraces at about 80 to 100 feet above the present flood plains. Below Forth township the flood plains widen, but the 30 foot terraces continue for a considerable distance downstream, particularly on the western side of the river, where it merges into the coastal plain that continues as far as Ulverstone. Between Forth and Leith, at the mouth of the estuary, there is a suggestion of a further terrace only a few feet above river level, but observations were not sufficient to confirm this. Leith, which is 40 feet above sea-level, is built on a coastal plain consisting of sand and shingle beds, grading at the coastline into storm beaches of shingle.

The mouth of the Forth Estuary was once a wide, deep bay, but it has been silted up into a flood plain as a result of the development of a bay-mouth bar from its western margin. This bar consists of a series of beach ridges of shingle, now several feet above high tide level, and covered by sand dunes about 20 feet high on their seaward side.

Leven River: At Ulverstone (50 feet above sea-level) the coastal plain, on which the town is built, becomes over a mile wide, and the section of it exposed in the banks of the Leven where the Nietta railway bridge crosses the river, shows 20 to 30 feet of silts and gravels at high water. This coastal plain decreases in height towards the sea, where it is fronted by sand dunes, and is not more than 10 to 15 feet above sea-level at the coastline.

Blythe and Emu Rivers: Between Ulverstone and Penguin the coastal plain is at first fronted by marshes (usually drained) formed behind the line of sand dunes that marks the cliff-line. Mid-way to Penguin, however, the Dial Ranges, which are composed of resistant Cambro-Ordovician sediments and formed a divide in the pre-basaltic landscape, come down to the coast, forming a high ridge almost at right angles to it. West of Penguin the Cambro-Ordovician sediments are capped by basalt,

but they outcrop again as a ridge more or less parallel to the coast from Blythe Head to Wivenhoe. All along this stretch of the coast an irregular wave-cut bench marks the shore-face, and this bench is backed by a sharp cliff, 20 to 30 feet high, cut in the narrow raised shore platform which forms the coastal plain.

The Blythe River has cut down to a depth of about 25 feet near its mouth through a narrow plain composed of sands and gravels, and a similar flat, 30 feet above sea-level, occurs at Wivenhoe, the most easterly suburb of Burnie. Where the Emu River crosses this plain a section of bedded shingle and sand, 20 to 25 feet deep, is exposed.

Burnie Township: At Burnie there appear to be two raised shore platforms. Burnie Park (West Burnie) and much of the central part of the town is built on a short platform about 40 to 50 feet above sea-level, while Burnie Beach (from the piers to the Showground) is backed by a lower flat, about 15 feet above sea-level.

The Cam River: From West Burnie to Somerset the road runs along a narrow strip of coastal plain, which is fronted by low cliffs and a ragged wave-cut bench, formed in the folded and contorted Cambro-Ordovician sediments. At Somerset the mouth of the Cam has cut down to a depth of about 25 feet through bedded gravels (Pl. VIII., fig. 9), which form a terrace on either side of the river, and merge with the adjacent coastal plain. The shape of the pebbles suggests that this deposit is probably a raised beach.

Wynyard Plain: Between Somerset and Seabrook (22 feet above sea-level) the coastal plain widens to about a mile, and west of Seabrook the scarp develops a deep, wide indentation. In this indentation lies the Wynyard Plain, which is 40 to 60 feet above sea-level. It extends from the right bank of the Inglis River, southwards for one and a half miles, and eastwards to the northern edge of Woody Hill. The plain is composed of sands and clays, but east of Stinking Creek it changes to coarse shingle. Loftus Hills (1913) considers that the sands and clays represent a silted up estuary, or lagoon that formed behind the shingle beach. Where the Flowerdale and Inglis Rivers cross this plain, they have cut valleys to a depth of 30 to 40 feet below its surface, indicating an emergence of the land of this order since the formation of the plain.

The shore-face, in the vicinity of Wynyard, is cut in soft Permo-Carboniferous strata, which have been planed off to a more or less smooth platform, only exposed at low water.

Wynyard—Table Cape—Jacob's Boat Harbour: At Wynyard the coastline turns sharply to the north, as far as Table Cape, and then turns westwards again to Jacob's Boat Harbour. Table Cape is an uncovered laccolith of analcite-dolerite (trachydolerite,

Twelvetrees, 1908), which has formed a buttress against marine erosion. This laccolith was uncovered before the adjacent basalt lava-flows were extruded, and they, in turn, are older than the Wynyard Plain, or the bay which it infills.

Between Wynyard and Table Cape these lavas overlie Tertiary and Permo-Carboniferous sediments, but west of Table Cape they pass below sea-level, and for a distance of about five miles the wave-cut bench and cliffs are formed of basalt. The cliffs rise over 200 feet high along this stretch, and are nearly vertical in their lower parts (Pl. IX., fig. 3). Approaching Jacob's Boat Harbour, the western wall of the old valley rises above sea-level, although several minor valleys, each filled by basalt, are encountered at sea-level before the Boat Harbour is reached.

At the Boat Harbour itself remnants of two shore platforms are preserved (Pl. IX., fig. 4). The higher one forms cliffs 20 to 30 feet high at the back of the beach, and extends back as a narrow gently sloping platform to the old sea-cliffs of the scarp, where it is about 50 feet above sea-level. The lower platform forms the flat-topped promontory, 300 yards long, and 50 yards wide, that protects the cove from the north-west wind. It is 10 to 15 feet above sea-level, and is being undercut at several places.

A further remnant of the upper platform occurs about half-a-mile east of the Boat Harbour, where a bluff of white quartzite, forming the interfluve between two of the smaller basalt-filled valleys that pass below sea-level, contains a niche which appears to be the remnant of a cave, at about 50 to 60 feet above sea-level. The cave—if it is one—is filled with angular debris from rock falls.

Stanley Peninsula: Stanley Peninsula (fig. 5) is a composite-tied island. The major part of the peninsula—the Green Hills—consists of a ridge of basalt (an old valley flow) tied to the mainland by a Y-tombolo, the lagoon of which has been drained (Pl. X., fig. 2). On either side of the tombolo, spits, which are about three miles long, have enclosed shallow arms of the sea. At low tide both inlets are dry except for central channels, which carry the drainage from streams flowing into them. A drain connects the inlets, and the workmen who dug the channel reported that the tombolo is underlain at a depth of a few feet by a bed of shells which is three feet thick. Excavations in other parts of the tombolo have confirmed this. In its narrowest part the tombolo is less than half-a-mile wide. Just within the mouth of the East Inlet a small spit has been built out in the reverse direction to the major spit.

The basalt ridge fills an old valley which sloped to the north, and passed below sea-level in that direction. Originally the basalt was probably connected with the extensive flows, now fronted by a scarp, in the vicinity of Forrest. Where the tombolo is

situated, the valley floor, which was composed of soft Permo-Carboniferous (?) sediments, passed above sea-level. Marine erosion was able to undercut the basalt filling here, in the manner indicated in fig. 2, and so convert the northern part of the basalt flow into an island.

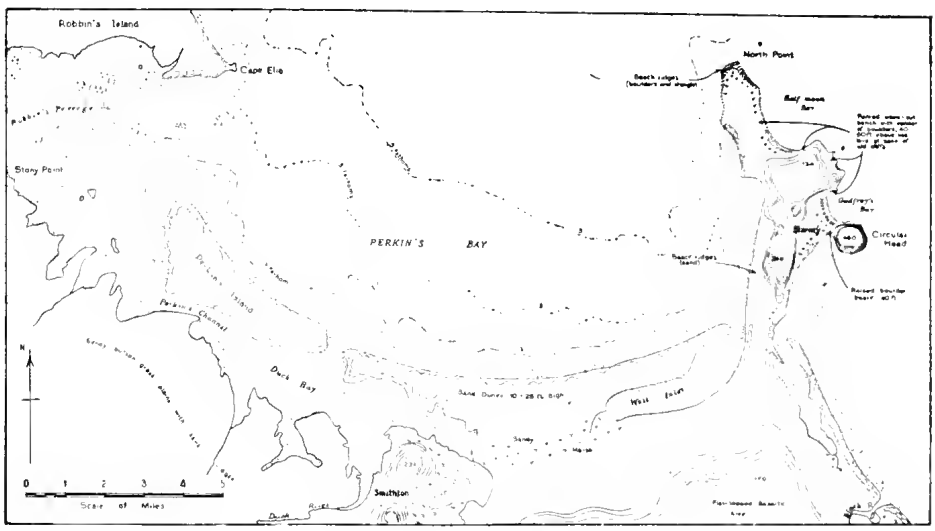

FIG. 5.—Map of Stanley Peninsula and Perkin's Bay (adapted from Admiralty Chart No. 3687. Folio 98).

On its western side the tombolo dies away about a mile north of its junction with the basalt ridge. About fifteen distinct sand ridges, separated by swales 2 to 3 feet deep occur on this part of it.

On its eastern side the sand bar and the low dunes which cap it extend as far as the township of Stanley, which is built in the shelter of Circular Head, and form part of the Y-tombolo which ties that one-time island to the Green Hills (Pl. X., fig. 1). The lagoon enclosed by this tombolo was still a swamp in 1826, when the Van Diemen's Land Company became established at Circular Head, but has since been drained. The shore platform beneath this tombolo is formed of a soft sandstone or mudstone, which outcrops at low tide at both ends of Godfrey's Beach, and also on the south-eastern side of Circular Head, between the old and the new wharves. The sand dunes backing Godfrey's Beach form a series of seven ridges, but this is largely due to the erection of brush fences, now buried, in an attempt to stem the landward advance of the sand. Two small streams, rising in springs and seepage at the foot of Green Hills, are conveyed in drains through the lagoon, until they lose themselves in the dunes, and a well at the western end of Godfrey's Beach, at the foot of the basalt ridge, supplies an abundance of good water, and was previously used for the town supply.

Basalt Ridge: The ridge consists of flows of basalt and olivine-nephelinite filling an old valley. At its southern end, where it is highest (250 feet above sea-level) the ridge is narrow and uneven, rising into several small eminences. Further north it broadens out into a level plain about 150 feet above sea-level. At the northern end the basalt passes below sea-level.

At the western end of Godfrey's Beach a junction of basalt with bedrock is exposed at low tide. The basalt is vesicular near the contact, and does not stand out in relief from the sediments. At about 15 feet from the contact it becomes dense and columnar, the columns being inclined at right angles to the slope of the valley wall. Finely laminated cross-jointing, at right angles to the axes of the columns, then becomes prominent, and enables the shape of the valley walls and floor to be determined. This valley, and another which joined it from the north-east, appear to have been tributaries to the main valley, which lay a little further to the west.

Where Godfrey's Beach meets the basalt ridge there is a remnant of an elevated shore platform, running up from 25 feet above sea-level at the present cliff, to about 40 feet at the old sea-cliff behind it. An exposure along the present cliff shows that this old bench is covered by a veneer of rounded boulders about 2 feet thick (Pl. VIII., fig. 8). The boulders include occasional pebbles of quartzite and reef quartz in addition to basalt and analcite-dolerite (from Circular Head). Half-a-mile further along the cliff there is a more extensive raised shore platform, about 30 feet above the present wave-cut bench, and running back to a height of 40 to 50 feet above sea-level (Pl. X., fig. 3). This bench also has a veneer of rounded pebbles. Rock-stacks have been cut from it in one or two places, and islets and rocks some hundreds of yards out to sea testify to the further extension of this shore platform—and of the basalt-filled valley—further out to sea. The present wave-cut bench is being formed in a layer of vesicular basalt, which has enabled the waves to undermine the more dense basalt in places, cutting small caves, a miniature arch, and, near the northern end of the raised platform, a small blow-hole.

Turning the point into Half-Moon Bay, still further traces of this raised shore platform can be observed (Pl. VIII., fig. 7), until the southern edge of that part of the Peninsula known as the Western Plain is met. On the western side of the Green Hills, further indication of emergence is found. The western shore is fronted with a beach almost half a mile wide at low tide, and as a result there is little wave erosion, or cliff formation along this stretch of the coast. The back of the beach is marked by a few pebbles, and a line of miniature sand dunes, which enclose a lagoon about 20 yards wide. From this lagoon there is a sharp rise of the land of from 15 to 20 feet in a matter of

a few yards, and then a narrow sloping plain rising to about 50 feet above sea-level in about 100 yards. The slope then steepens to the steep side of the basalt ridge. This raised strip of plain, which runs along the whole western side of the Green Hills appears to be an old shore platform.

Western Plains: The Western Plains (Pl. X., fig. 4) form a low-lying north-westerly extension of the peninsula, about three miles long, and one mile wide. Where it joins on to the Green Hills it is faced by a scarp as marked as that along either side of the basalt ridge elsewhere. The surface of the plain is not wholly flat, and in its central part there are one or two gentle hills that rise to 70 to 80 feet above sea-level, and show an occasional outcrop of large angular boulders of basalt. Midway along the north-eastern shore, there is a cliff face, about 20 feet high, in which decomposed basalt is overlain by a veneer of rounded pebbles and boulders similar to those overlying the raised platform at the western end of Godfrey's Beach. This veneer is about 3 feet thick, and contains occasional pebbles of quartzite. There can be little doubt, therefore, that this is an old raised shore-platform and pebble beach. The surface of the platform and beach rises inshore to a height of about 35 to 40 feet. The probability is, therefore, that the Western Plains are largely a raised shore platform cut in a basalt-filled valley which passed below present sea-level, and was a tributary to the main Green Hills valley.

Much of the Western Plains, however, is of secondary origin. All along the north-eastern, and along a considerable extent of the south-western shore, extensive beach ridges of pebbles and boulders of basalt have been built up to a height of 15 feet above sea-level (Pl. VIII., fig. 10). The successive ridges are occasionally as wide as 20 feet, and are separated by swales 2 to 3 feet deep. In the vicinity of North Point, a series of such ridges has been built up to a total width of about 200 yards. Sand has accumulated to some extent behind these ridges, but the wind is too strong for dunes to form, except where the plain meets the Green Hills ridge. However, quite extensive marshes and lagoons have formed behind the pebble ridges, especially in the northern part of the plains. Kelp and seaweed act as the cementing medium to the pebbles. In places one can observe the old shore platform descending abruptly to these pebble beaches, almost as a cliff.

Circular Head (The Nut): Circular Head is the remains of a small steep-sided laccolith. It consists of gigantic columns of analcite olivine-dolerite, 4 to 6 feet in diameter, and rising to a height of 400 feet above sea-level. The columns are vertical, and in places form vertical cliffs several hundred feet high, with a fringe of steeply sloping scree around their lowest part (Pl. IX., fig. 1).

The top of the Circular Head is not as flat as appears from a distance, and two small valleys, which junction, form a hanging valley about 80 feet deep on the southern side, indicating that a valley ran in that direction prior to the erosion of the sedimentary walls of the laccolith.

Stanley is built on an old pebble beach, 30 to 40 feet above sea-level, at the foot of the Head. Limpets have been found associated with the pebbles (Nye, 1938, p. 8), and two such shells were secured from excavations in progress in the basement of the Post Office, in association with water worn pebbles. This material may not have been *in situ*, however.

Receding Spit and Siltation of Stanley Harbour: The Eastern Spit is receding. Mr. Partridge, the editor of the *Circular Head Chronicle*, informed me that it has receded about half-a-mile during his fifteen years of residence at Stanley. This recession appears to have been in progress for a considerable period. Thus Stephens (1908, p. 765) states that whereas the original track to Stanley followed the East Spit, and easily forded the bar across the mouth of the inlet at low tide, by 1908 (or earlier) the channel had deepened so that travellers had to strike inland after crossing the Black River, and follow the tombolo.

If the recession of the spit continues, it will leave the tombolo, which carries the road and railway, exposed to the action of storm waves at its narrowest part. Efforts are being made to stem the recession by planting marram grass along it, but if, as seems probable, the recession is due to wave action rather than the wind, and is related to the stage which the coast line has reached in its development, these efforts will meet with little success.

The sand from this receding spit is being carried northwards, and is silting up Stanley Harbour, at the rate of about one inch a year, according to a report issued by the Marine Board, about 40 years ago. This conforms with the fact that the ship *Caroline*, of 330 tons burden, which came to Stanley in 1828 (Hare, 1928) berthed at the inside part of the old wharf, where to-day a small yacht can barely find sufficient water at high tide, and where the sand is bare at low tide. Since the *Caroline* would draw at least 8 feet of water, and would probably require a foot or two of water to spare, at least 96 inches of sand have been deposited in the last 100 years. Bathing boxes which were in use fifteen years ago are now so far removed from water deep enough to swim in, even at high tide, that they have been abandoned; and the place where it is reported that a 300-ton schooner was built and launched in the early days is now about 100 yards from the high tide mark.

Godfrey's Beach, on the other hand, does not appear to be silting up, and the sand dunes are sometimes subject to attack by storm waves. Thus a storm during Easter, 1939, swept away

30 feet of dunes. Wind is constantly blowing the sand inshore; and the storms, according as they come from the north-west or the north-east, shift the sand from one end of the beach to the other. This trend has been active since 1837 (Gunn, 1854).

III. The Emergent Coastline.

Perkin's Bay: The sand bar which forms the three mile long spit on the west side of Stanley Peninsula (fig. 5) continues westwards in an unbroken curve as far as the mouth of the Duck River, a distance of eight miles. At its western end, as at the eastern, the bar forms a spit about three miles long, here enclosing the eastern arm of Duck Bay. On the other side of the narrow channel through which the Duck River discharges into Perkin's Bay, the sand bar forms again as the dune-covered Perkin's Island (wrongly shown on geological maps of Tasmania as composed of basalt), and continues in the same sweeping curve for another four and a half miles, as far as Robbins' Passage. Between the bar and the mainland is a channel from half-a-mile to a mile and a half wide, which is very shallow, being largely exposed sand at low tide; and for a distance of about three miles, between the east arm of Duck Bay and West Inlet, the channel has been converted into a sandy marsh, which joins the bar to the mainland. The excessive silting and sanding up of this stretch of the channel is probably due to the fact that this strip of the bar is most exposed to strong winds from the sea, whereas other parts of the bar are relatively sheltered by Stanley Peninsula and Robbins Island.

On the seaward side, soundings show that the sea-floor is very shallow, and has a very gentle slope. The presumption is, therefore, that this bar is an off-shore bar which has been joined to the mainland by silting of part of its lagoon. The breach in the bar at the mouth of the Duck River appears to be stationary, but the disposition of sand off the mouth suggests that a certain amount of westerly beach-drifting is in progress.

The origin of the bar is, no doubt, related to the features of recent emergence described in the next section.

Smithton to Woolnorth and Marrawah: Between Smithton (Duck River) and Woolnorth Point and Marrawah, the compound nature of the coast is prominent. In plan the coast has the outline of a relatively youthful coast of submergence (fig. 6). Drowned river mouths and off-shore islands of various sizes point to drowning of an extensive river system.

Siltation of the estuaries, followed by emergence, has given rise to an extensive coastal plain 20 to 25 feet above sea-level, which rises gently to 50 feet or more as it is followed inland. The plain extends inland for several miles in places, and merges into a series of five large swamps—Mowbray Swamp (two arms), Briton Swamp, Montague Swamp and Welcome Swamp, each of which is about 100 feet above sea-level where crossed by the

Smithton-Marrawah road. These swamps are separated from one another by ridges rising 100 to 200 feet above the level of the swamps. The most easterly of them, the Christmas Hills, is the most prominent, and is capped in places by basalt. The Welcome Swamp on its west side abuts against the basalt capped plateau (The South Downs) near Marrawah.

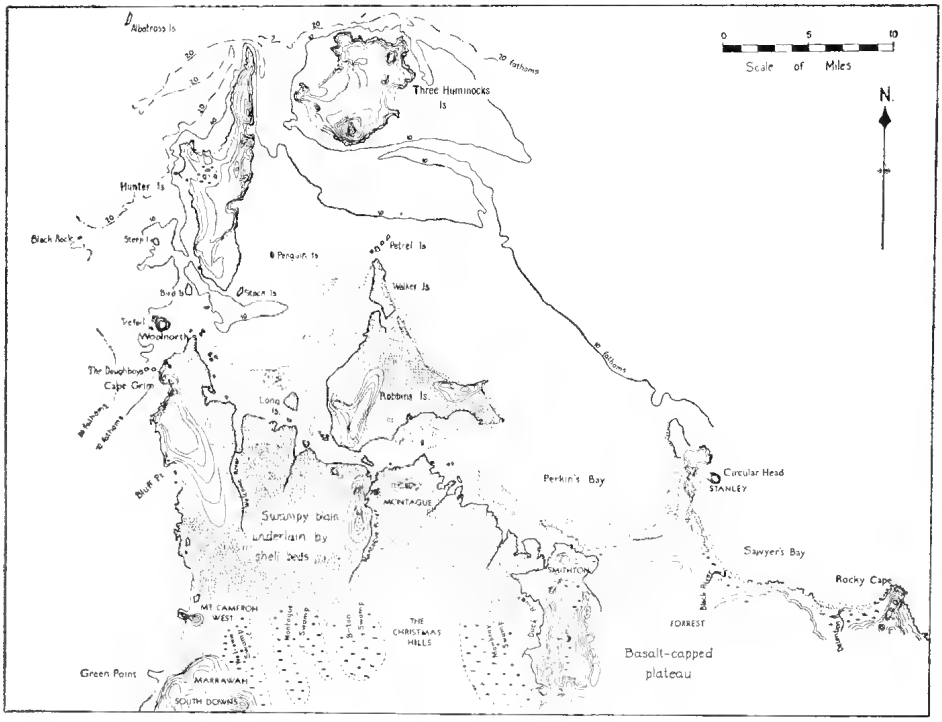

FIG. 6.—Map of the Emergent Coast, west of Smithton (adapted from Admiralty Chart No. 3687, Folio 98).

The thickness of the sands forming the plain, and the shape of the underlying bedrock are unknown, but in places along the Duck River the sands are only 15 feet thick. Marine shells, regarded as Pleistocene, have been found at depths of 6 to 10 feet at various parts of the plain, near Smithton (Nye, 1934), and in the vicinity of the Welcome River, while freshwater shells and marsupial remains were found associated with peat during the draining of the eastern arm of Mowbray Swamp (Nye, 1934, pp. 59, 60 and refs.); so that while marine conditions dominated near the mouth of the original bay, they gave way to estuarine conditions towards the bay head. A similar gradation has been observed on the Deep Creek Plain, east of Smithton (Nye, 1934). These two contemporaneous plains are separated by a long ridge of resistant dolerite dyke and its adjacent sedimentary wall rocks (Pl. IX., fig. 7). The Deep Creek Plain

rises about 100 feet above sea-level, and this leads Nye (1934, p. 61) to suppose that the Duck River Plain also may have been higher originally, but may have undergone erosion since its emergence. The presence of old dune ridges on the Duck River Plain, and on the stretch of plain between Montague and Woolnorth Point, suggests, however, that the present surface is more or less the original one.

The Duck River flows in a meandering course across the plain, near Smithton, and has cut down its bed to a depth of 15 to 20 feet into the sands and underlying bedrock, but has not formed flood plains at the new level. Deep Creek, on the other hand, has formed a small flood plain, or marsh, below the level of the plain, at its mouth.

The level of the coastal plain is broken by isolated sand ridges trending more or less parallel to the coastline, and by occasional ridges of older rocks rising 200 to 400 feet above sea-level. These ridges of older rocks may be designated resumed islands since, prior to the emergence of the coastal plain they formed coastal islands similar to those in existence off the present coastline (fig. 6), and were restored to the mainland by the emergence rather than by any silting process. Such resumed islands are represented by the basalt-capped hills on which the village of Montague is built; the basalt ridge at Montague West; the adjacent hills of Cambro-Ordovician sediments; the high land stretching southwards from Woolnorth Point to Bluff Point, and fronting the sea with the precipitous cliffs of Cape Grim; the small dome-shaped laccolith of Mt. Cameron West (Pl. X., fig. 5); and possibly the basalt-capped plateau of the South Downs at Marrawah. Two similar resumed islands, formed of basalt ridges, occur on Robbins Island, surrounded by a similar emergent plain.

Woolnorth Point: Just west of Woolnorth Station are the remains of old rock stacks and sea-cliffs, cut in Cambro-Ordovician sediments, and fronted by indurated beach or dune sands, which form a narrow coastal plain 40 to 50 feet above sea-level. The present shore consists of an irregular wave-cut bench, cut in steeply dipping sediments, interspersed with pocket beaches. Close to Woolnorth Point a series of beach ridges of shingle about 80 yards wide have been built up to a height of 5 to 6 feet above high water mark (Pl. IX., fig. 8). The pebbles are chiefly of olivine-basalt, presumably derived from Robbins Island, or from some of the smaller islets off the coast, whose geological characters are not shown on geological maps. The ridges are 3 to 4 feet wide, and separated by swales 1 to 2 feet deep. The inner ridges tend to be grass-covered, and lead back to low cliffs cut in the raised shore platform.

The old sea-cliffs west of Woolnorth Station mark the northern end of the large resumed island that extends southwards as far as Studland Bay (fig. 6). Along its western side this island is

exposed to the south-west winds which bring frequent heavy storms against the shore. Marine erosion has destroyed all trace of the coastal plain on this side of the resumed island, and has cut steep cliffs, up to 200 feet high, in the higher land of the old island (Pl. IX., fig. 5). The cliffs are being undermined, with the formation of caves, and their rapid recession is attested to by the occurrence of the Doughboy Islets, off Cape Grim (Pl. IX., fig. 6). These two islets were attached to the mainland at no distant date, but the sea has cut channels between them and the mainland.

Trefoil Island, some distance to the north-west, has a similar cliffed coastline.

Marrawah: A beach four miles long stretches from Green Point, west of Marrawah township, northwards to Mount Cameron West, which is a small, steep-sided laccolith of analcite-olivine dolerite (Pl. X., fig. 5). Sand dunes extend the length of the bay, rising as high as 60 feet in its central part. Behind the dunes are the extensive marshes of the coastal plain, which extends back to a steep scarp about 300 feet high. The scarp consists of old sediments capped by an unknown thickness of Miocene limestone, and about 100 feet of basalt. Remnants of an old shore-platform about 50 feet above sea-level can be observed in places at the foot of the scarp.

Green Point appears to be a tied island, joined to the mainland by a Y-tombolo which encloses a small marshy lagoon, but there may be a rock connexion with the mainland beneath the sand dunes on the northern side of the tombolo. Green Point itself appears to be another remnant of the raised shore platforms found at the foot of the scarp.

At the southern end of the beach leading to Mt. Cameron West, the dunes are intact, but at the northern end they are subject to strong south-westerly winds, and the sand has been blown inland for a distance of over a mile. This has exposed beds of a Recent shelly limestone beneath the dunes. Exposure has been aided by wave erosion, which has cut a cliff in the dunes and limestone adjacent to Mount Cameron West.

The limestone consists of sand and comminuted shell fragments with occasional whole shells. Adjacent to Mt. Cameron West its top is 25 to 30 feet above sea-level, but a gentle southerly dip carries it below sea-level in about half a mile. The limestone is brownish coloured, compared with the white to earthy-white colour of the dunes, and the upper beds have been indurated with limonite and lime, the latter mostly in the form of tubular calcareous concretions. The indurated beds stand out in relief as the result of wind etching. Close to Mount Cameron West, where there is a rapid run-off for rain water, the limestone has been eroded into a small area of badlands. At this point the sandy cover has been stripped completely from it. The fossil content of these beds (recorded in the Appendix) proves that they are

of Quaternary age, so that their present position above sea-level indicates an emergence of the shore line in relatively recent time. Similar beds occur on the north side of Mt. Cameron West, and also at a distance of about two miles north of the Mount, at a similar elevation above sea-level (Meston, 1932).

North of Mt. Cameron West are further beaches, divided at intervals by reefs of rock (projecting wave-cut benches) and backed by sand dunes. The dunes are being blown inland into the swamps that extend for some miles behind them, and cuspate lagoons, or lakes, lie between the swamps and the inner fringes of sand.

Springs of fresh-water occur on the part of the beach exposed at low tide at two points between Green Point and Mt. Cameron West. At one place one spring was observed (close to the Marrawah picnic ground), while at the other seven springs formed a cluster. The drainage from the marsh behind the dunes apparently seeps through the sand along the surface of the buried shore-platform, and when the "head" becomes sufficient, issues as springs on the sea-side of the dunes, causing the sand to "boil" in small circular depressions which overflow to the sea. The largest pool measured 3 feet in diameter. The relation of these springs to the shore-platform suggests that the shore-platform continues for a considerable distance inland, as the floor of the marshes.

Towards the northern end of the beach, where wind action is stronger, the heavy seas have thrown up a storm beach of pebbles and boulders, and where these have filled the mouths of streams through the sand dunes, permanent waterways are maintained, for even when the pebble-filled stream mouths are covered over with sand, the water can easily percolate between the pebbles. As a result the streams at this end of the beach are not blocked by intermittent sand-bars as is found more usually along the Tasmanian coast.

The Raised Shorelines.

The observations given above indicate that remnants of at least two raised shorelines can be found at intervals along the north-west coast of Tasmania, one at 5 to 15 feet above sea level, and the other at 40 to 50 feet above it, thus confirming the observations of Lewis (1934, p. 82); and that a number of the rivers flowing into Bass Strait along this stretch of coast show a development of terraces in their valleys at corresponding heights above their present levels.

The 40 to 50 feet strandline is the more pronounced of the two, and can be traced from the Rubicon Estuary as far as Marrawah. The 5 to 15 feet strandline is more difficult to establish. In many places there are wide shingle beaches up to 10 feet, or even more, above sea-level. These beaches fall steeply to the water-line, and sometimes lagoons are impounded behind

them, but it is probable that many, if not all, of them have been formed by storm waves acting at present sea-level. Some doubt must also attach to wave-cut benches which project only a few feet above normal tide level. Such benches could be due to storm waves as easily as to emergence. At some localities, however, as at Jacob's Boat Harbour, there are undoubted remnants of the 15 feet strandline.

There is also a suggestion, in the form of doubtful river terrace remnants in the Mersey and Forth valleys, of the existence of a third strandline at about 100 feet above present sea-level, but this could not be confirmed.

The occurrence of raised beaches and shore platforms along the northern coast of Tasmania and the islands of Bass Strait was first recorded by Johnston (1888), who noted the occurrence of *Helicidae* sandstones at heights up to 100 feet above sea-level on Cape Barren Island, Badger Island, Chappell Island, Green Island and Kangaroo Island, in the Furneaux Group, and a raised beach about 100 feet above sea-level on Chappell Island. On Badger and Green Islands he recorded a series of shelly beaches invariably 40 to 50 feet above sea-level, and sometimes nearly a mile from the shore, while on Flinders Island he found a stratified bed of oyster shells in the banks of the Arthur River, about two miles above its mouth, and 30 feet above sea-level. In addition he noted comparable features "on other places along the northern coast of Tasmania," as well as "subordinate valleys within main ones," and river terraces in the valleys of the chief rivers debouching into Bass Strait. Later workers have confirmed Johnston's observations. Twelvetrees (1908, p. 165) states that raised beaches "exist all along the northern coastline and in the Straits islands. Elevated beaches of marine shingle are seen at the mouths of the Blythe and Emu Rivers, and elsewhere along the shore of Bass Strait." Lewis and Nye (1928, p. 27) write that "the whole coast shows a recent uplift, and a very marked shore platform exists, particularly from Devonport to Stanley." David (1923) has recorded a raised beach 3 to 4 feet above high-water on the Tamar, near Launceston; and Lewis (1934) records raised beaches at 5-15 feet and 40 feet above sea-level in the vicinity of Burnie.

Submerged Shorelines.

Evidence points to the existence of at least one, and probably two, submerged shorelines. The submarine contours of the Tamar Valley can be traced on Admiralty Chart No. 3649, Folio 98, for a distance of 3 to 4 miles out to sea. The valley form can be followed to a depth of 15 fathoms, and with less certainty to the 20-fathom contour, indicating the existence of a submerged shoreline at a depth of about 120 feet below sea-level. Similarly, in the vicinity of Hunter Island and Three Hummocks Island, in the extreme north-west (fig. 6), the contours of submerged valleys can be traced on the Admiralty Chart, No. 3649, Folio 98.

to depths of 25 fathoms, but apparently do not continue to greater depths. Here, then, the submerged shoreline lies at about 150 feet below sea-level.

The many basalt-filled valleys that pass below present sea-level provide further evidence of a submerged shoreline some distance out to sea from the present coastline; but there is a suggestion that this shoreline is older than the 120 to 150 feet submerged shoreline. Thus, if the basalts in the Stanley-Smithton-Montague district are regarded as of similar age, then the basalt-filled valleys on Robbins Island must be older than the submerged valleys that lie between Robbins Island and Hunter and Three Hummocks Islands. Again, the Tamar has breached a basalt flow extending from Beauty Point via Garron Rock to near Georgetown. The base of this flow, whose valley section is clearly shown at Beauty Point, lies well below the present estuary level, but above its floor. Again, the basalt-filled valleys in the Wynyard-Table Cape district are considerably older than the valley which was drowned to give rise to the Wynyard Plain. No depth can be suggested for this possibly older shoreline.

Origin of the Oscillating Shorelines.

It seems highly probable that these movements in the position of the shoreline are directly related to the eustatic rise and fall of sea-level during Glacial and Post-Glacial time. Lewis (1934) from his studies of the river terraces in the valley of the Derwent and other rivers in south-eastern Tasmania has shown that a definite sequence of alternating periods of high sea-level and low sea-level can be established in that part of Tasmania. During the periods of high sea-level flood plains were formed at heights of 100 to 150 feet, 25 to 60 feet, and 5 to 15 feet, respectively, above present river level. During the intervening periods of low sea-level, troughs were cut in the respective flood plains to depths of 250 feet, 100 feet, and 20 feet, in each case leaving residuals of the former flood plains as paired terraces. He concluded that these terraces were the outcome of the eustatic changes of sea-level during the Pleistocene and that the raised shorelines at 100 feet, 40 to 50 feet, and 10 to 15 feet, above sea-level, which he and other observers had noted, particularly along the northern coast of Tasmania and the islands of Bass Strait, were developed contemporaneously with the river terraces during the high sea-levels of the interglacial stages. On this basis he correlated the three series of river terraces and raised shorelines with the known glacial stages in Tasmania, as follows:—

Terrace System.	Age Correlation.
Uppermost terraces and beaches 100-150 ft. above sea-level.	Pre-Glacial sea-level (Pre-Malanna).
Middle terraces and beaches 45-50 ft. above sea-level.	Malanna-Yolande sea-level.
Lowest terraces and beaches 5-10 ft. above sea level.	Yolande-Margaret sea-level.

This is to assume that the Pleistocene glacial stages in Tasmania were contemporaneous with the glacial stages in other parts of the world. This may well have been so; but it is clear that the amount of ice involved in the glaciation of Tasmania, even at its maximum, would not have caused an eustatic rise and fall of sea-level of the magnitude concerned. Assuming that ice covered an area of 25,000 square kilometres of Tasmania to the improbable depth of 2,000 metres, then the amount of water involved would be of the order of a layer 10 centimetres thick over the surface of the ocean. In other words, the eustatic changes of sea-level which affected Tasmanian river-valleys and shore-lines were independent of the glaciation of Tasmania, and are to be correlated, therefore, with the glacial stages of the Great Ice Caps. Whether these existed contemporaneously in the Northern and Southern Hemispheres remains to be proved, but if one waxed while the other waned, then (i) the maximum possible eustatic change of sea-level would have been reduced accordingly; and (ii) the duration of the periods of high and low sea-level would have been prolonged. In view of the magnitude of the observable changes of sea-level, there can be little doubt as to the broad contemporaneity of the successive glacial and interglacial stages throughout the world.

It follows then, that though Lewis was probably right in ascribing the changes of sea-level to this cause, the river terraces and marine terraces of Tasmania must be correlated with the stages of the Pleistocene as revealed in North America and Northern Europe, rather than as revealed in Tasmania, where the record is not complete. On this ground it is necessary to account for three interglacial periods of high sea-level, rather than two. Moreover, as Daly (1934) has shown, there is considerable evidence of a further eustatic fall of sea-level in Post-Glacial time, of the order of 15 to 20 feet, so that if the record is complete, we should have four sets of terraces to search for, rather than the two implied by the glacial record in Tasmania.

If Daly is correct, it seems likely that the 5 to 15 feet terraces and shore platforms have developed from the Post-Glacial fall of sea-level, in which case the 40 to 50 feet strandline may correspond to the Third Interglacial Stage (Riss-Würm), and the 100 to 150 feet strandline to the Second Interglacial Stage (Mindel-Riss). Their heights above sea-level are about the correct magnitude, judging from the figures given by Daly (1934) for such terraces in Europe, Northern Africa and Northern America.

Of the two submerged shorelines recognized in the present study, the one at 120 to 150 feet below sea-level corresponds in magnitude to the first fall of sea-level measured by Lewis (1934) in the Derwent Valley, and is older than the 40 to 50 feet raised strandline, but presumably younger than the 100 to 150 feet raised strandline. It would correspond, therefore, on the suggested correlation, to the Third or Riss Glacial Stage. The pre-basaltic

submerged strandline would correspond to an earlier Glacial Stage. In the Wynyard district the pre-basaltic valleys cannot be younger than the Second Glacial Stage, since the Wynyard Plain was formed in a valley cut in the basalts. The occurrence of what appears to be a remnant of a 100-feet terrace at Paloona in the Forth Valley suggests that the Forth Valley was formed during the Second or Mindel Glacial Stage. If this was so, the fact that the Forth Valley cut through the basalt sheet capping the plateau, and extending to the coastal scarp, suggests that the basalt-filled valleys passing below sea-level were probably formed during the First or Günz Glacial Stage. This suggestion must be accepted with considerable caution, however, since the basalt-filled valleys might have been brought to their present position by extensive Inter-Glacial faulting, parallel with the coastline, but located some distance inland from it.

Appendix.

Fossil Assemblage from raised beach deposit immediately south of Mt. Cameron West, near Marrawah (N.W. Tasmania).

Foraminifera (determined by W. J. Parr).

Gaudryina cf. *hastata* Parr.
Triloculina insignis (Brady).
Triloculina trigonula (Lamarck).
Bolivina sp.
Discorbis dimidiatus (Jones and Parker).
Discorbis australensis Heron-Allen and Earland.
Cibicides sp. aff. *pseudoungerianus* (Cushman).
Elphidium imperatrix (Brady).
Elphidium macellum (Fichtel and Moll).

Bryozoa (Determined by L. W. Stach).

Crisia acropora Busk.
Cellaria setigera Pergens.
Cellaria tenuirostris (Busk).
Vittaticella crystallina (Thomson).
Scuticella ventricosa (Busk).
Adeonellopsis sp.
Retepora sp.

Echinoidea (Determined by L. W. Stach).

Amblypneustes ovum pachista Clark.

The assemblages listed above are characteristic of recent shore deposits from the south-eastern Australian coast.

In addition to the above forms, the following contemporaneous land forms, presumably wind blown, were present.

Mollusca (Determined by C. J. Gabriel).

Laoma penolensis Cox.
Succinea australis Ferussac.
Charopa albanensis Cox.
Flammulina marchiana Cox.

My thanks are due to these gentlemen, and to Dr. F. A. Singleton, of the University of Melbourne, for their generous help in this connection.

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Explanation of Plates.

Plate VIII.

1. Tree stumps outcropping at low tide at Badger Head Bay, with West Head in the background.
2. Bed of peat outcropping at low tide at Badger Head Bay, with dune remnants capping the low cliff in the background.
3. Bed of peat outcropping beneath the storm beach, on its seaward side, Badger Head Bay.
4. Shingle ridge thrown up by storms, on the backshore at Badger Head Bay.
5. Close view of the tree stumps shown in Fig. 1 above.
6. The transition from stationary dunes to eroded dunes, where the dunes become exposed to westerly winds blowing past Badger Head.
7. Raised shore platform, 30 to 40 feet above sea-level, at the south-eastern end of Half Moon Bay, Stanley Peninsula.
8. Raised boulder beach capping the remnant of raised shore platform at the western end of Godfrey's Beach, Stanley Peninsula.
9. Section of raised shingle exposed in the road cutting at the Cam River.
10. Beach ridges of shingle near North Point, Stanley Peninsula.

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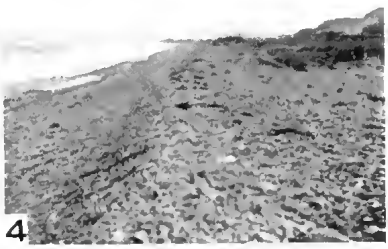
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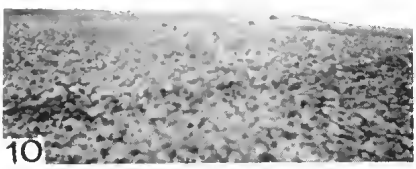
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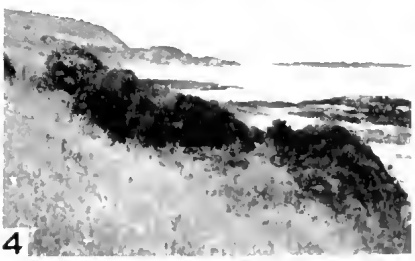

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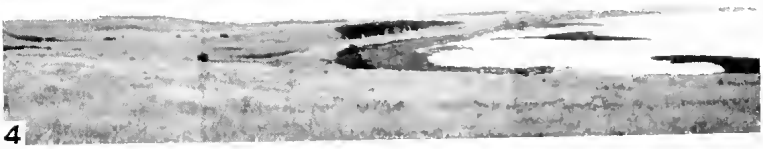
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Plate IX.

1. Raised sea cave, 50–60 feet above sea-level, at Rocky Cape.
2. Rocky Cape, from midway between the Black and Detention Rivers, showing the dip slopes towards the sea, and scarp slopes to the south.
3. Coastline between Table Cape and Jacob's Boat Harbour, where the basalt passes below sea-level. Rocky Cape can be seen in the background.
4. Jacob's Boat Harbour, showing the occurrence of two raised shore platforms, one at 10–15 feet above sea-level, the other at 40–50 feet, backed by a basalt-capped scarp, representing the old cliff line.
5. Cape Grim, showing the active formation of caves at present sea-level.
6. The Doughboys, off Cape Grim.
7. The Duck River Plain, where it abuts against the scarp formed by the dolerite ridge running south from Smithton. The scarp, in part at least, represents old sea-cliffs.
8. Shingle ridges near Woolnorth Point, with a raised shore platform in the background.

Plate X.

1. Circular Head, Stanley, an analcite-olivine-dolerite laccolith, joined to the main part of Stanley Peninsula (right) by a Y-tombolo. The hedge in the right middle-ground marks the edge of a raised shore platform.
2. The main basalt ridge of Stanley Peninsula (The Green Hills) tied to the mainland by a narrow tombolo. Portions of the spits on either side of the tombolo can be seen.
3. Raised shore platform, with capping of boulder beach, where the Green Hills basalt passes below sea-level, Stanley Peninsula.
4. The Western Plains, Stanley Peninsula, near their junction with the Green Hills ridge. A shingle ridge, capped by sand dunes, has enclosed a small lagoon, now drained, near the seaward edge of the raised shore platform, and the curved spits of shingle are building out the shore.
5. Mount Cameron West, a "resumed" island formed by a laccolith of analcite olivine-dolerite, from the south. Remains of a raised shore platform can be seen on the seaward side of the headland. The dunes adjacent to the mount cap beds of Recent limestone that have been raised 25–30 feet above sea-level.

[Proc. Roy. Soc. Victoria, **53** (N.S.), Pt. II., 1941.]

Art. IX.—*Studies in the Physiology of Host-Parasite Relations.*

1. The Effect of *Bacterium solanacearum* on the Water Relations of Plants.

By B. J. GRIEVE.

Botany School, University of Melbourne.

[Read 12th September, 1940; issued separately 26th July, 1941.]

I. Introductory.

It is proposed in this series of papers to examine selected pathological conditions in plants brought about by parasitic infection, in an endeavour to obtain a deeper insight into the physiology of host-parasite relations, with special reference to stimulation effects and wilting. For the purpose two xylem parasites, *Bacterium solanacearum* and *Fusarium lycopersici,* a phloem parasite *Aplanobacter Michiganense,* and a virus Spotted Wilt of tomato, have been selected for study. The present paper is devoted to an examination of the effect of invasion by *Bacterium solanacearum* on the water relations of host plants.

Plants infected by this organism frequently show as first symptoms epinasty of leaves, and the production of adventitious roots on the stem. Leaf epinasty is followed by unilateral flaccidity of leaflets, and finally the plant shows severe wilting. The march of transpiration and of absorption was determined during these successive phases, and correlated with the degree of invasion. The theories put forward by other workers and the belief that the wilting effect may be due to—(*a*) gum formation, (*b*) tylose formation, (*c*) toxins, (*d*) mechanical blocking, are examined in the light of these and other experimental results obtained.

II. Experimental Methods.

1. *Material:*—Tomato plants (variety Marglobe) and potato plants (variety Carman) were used as experimental material. A pure culture of *B. solanacearum* isolated from potato tubers served as the source of inoculum.

2. *The Measurement of Absorption and Transpiration:*—Weighing potometers were used for the determination of absorption and transpiration in healthy and infected plants. For experiments extending over one to two weeks (using tomato plants 8 to 9 inches in height), a tower type of potometer with vertical side-arm absorption tube was found suitable, while a small flask potometer fitted with a horizontal absorption tube served for short-term experiments using smaller plants.

Weighings of the tower type potometers were made on a transpiration balance and of the smaller flask type on a precision balance. Absorption values were obtained in each case from the calibrated absorption tubes. To minimize errors due to hydrostatic pressure effects in the vertical absorption tubes of the larger potometers, the meniscus movement was limited to 3 cm. before readjusting. Corrections were also made for volume variations due to temperature changes. Experimental plants were grown to a suitable size in washed sand watered with Shive's No. R5 C2 solution (1915) and after the roots had been washed free of sand the plants were transferred to the potometer. The method of removal of a plant from the sand in which it had been growing was to flood the container by placing it sideways in a larger container full of water. By gentle movements of the plant the roots were then disengaged from the sand without injury, and after further washings the plant was ready for insertion in the potometer. A short length of vaselined cotton wool was wound round the base of the stem which part was inserted into the appropriate slit in the rubber cork. The apparatus was then assembled, all air bubbles being eliminated. The potometer flask had previously been filled with boiled and cooled Shive's solution. Luting wax was used to give a watertight seal. After setting up, the plant was left for several hours, generally overnight, to recover from any "transference reaction." Algal growth in the culture solutions was inhibited by the use of brown paper shields.

The nutrient solution was maintained in each container by means of a reservoir connected by a tap and the solution itself was changed every third day in the case of tower potometers and each day in the case of the flask potometers. In long term tests the growth of the experimental plants was quite comparable to that of plants which were kept growing in sand culture.

For the determination of transpiration alone, plants were grown in metal or glazed containers, and when ready for use rubber covers were fixed in position. Loss in weight over specified periods was taken as a measure of the transpiration. Water was added daily to bring the containers back to their original weights. Evaporation and temperature records were kept during experiments. The plants selected for experimentation were of similar size and equal vigour. For comparative experiments they were grouped in pairs of closely similar size, and the containers were so arranged on the greenhouse bench that all were exposed to approximately the same environmental conditions.

For comparing the rates of water loss from intact leaves and leaflets of healthy and infected plants, Livingstone and Shreve's cobalt chloride method (1916) was followed, while a delicate torsion balance was utilized for comparing the rates of water loss

from detached leaflets of healthy and invaded plants. The procedure using the torsion balance was to cut off the companion leaflets, vaseline the cut ends, then weigh each as rapidly as possible. The leaflets were then suspended in still air, weighings being at hourly intervals for three hours.

3. *Leaf Area Determinations:*—When leaf areas were obtained at the close of an experiment the blue print and planimeter method was used. For daily leaf area determinations in tomato and potato, the special methods developed by Porter (1937) and Clements and Goldsmith (1924) were followed. When an experiment was carried to the wilting phase of disease the turgidity of wilted leaflets was restored by floating them on water for half an hour.

4. *Inoculation Technique:*—The organism was introduced by prick inoculation into the xylem of stem or root of the test plants as specified in the text. Control plants were pricked with a sterile needle.

5. *Histological Technique:*—To facilitate estimation of interference with water movement in infected plants, the procedure was adopted of cutting off the tips of roots at the end of an experiment and placing the plants in eosin solution for half an hour. Sections for microscopical examination were then cut at the bases of all petioles and at different root and stem levels. Material for paraffin sectioning was fixed in 70 per cent. alcohol and nitric acid. This prevented the diffusion of the bacteria from the vessels. Rawlins' modification of Stoughton's method (1933) was frequently employed for staining.

III. The March of Transpiration in Relation to the March of Invasion.

To obtain as complete a picture as possible of the influence of bacterial invasion on the transpiration relations of inoculated plants, experiments were carried out under three sets of environmental conditions which markedly affected the speed of invasion and the reaction of the host plant to it. These were as follows:—

(*a*) In a glasshouse during summer months (rapid invasion).
(*b*) Under deep shade conditions in a glasshouse during summer months (moderately rapid invasion).
(*c*) In a glasshouse during autumn months (slow invasion).

(*a*) Transpiration Relations when Invasion is Rapid.

Experiment 1.—Eight healthy tomato plants 9 to 10 inches in height were selected and grouped in pairs. The members of each pair were very similar in height and bore the same number of leaves. Transpiration was recorded during a preliminary two-day period, after which one plant of each pair was prick inoculated

in one bundle near the base of the stem. Transpiration records were continued until the inoculated plants were wilting. The results of the experiment are embodied in Table I. and text figs. 1.

TABLE I.—PROGRESS OF INVASION AS INDICATED BY SYMPTOMS. EXPT. I.

EXPT. PLANT.	TIME IN DAYS AFTER INOCULATION.					
	1	2	3	4	5	6
1 (8 leaves)	—	—	2 leaves showing unilateral wilting	3 leaves wilting; 3 more wilting unilaterally	6 leaves wilting; 1 leaf unilaterally wilted; 1 leaf flaccid	All 8 leaves wilting
3 (9 leaves)	—	—	—	1 leaf wilting; 2 leaves showing unilateral wilt; 1 leaf flaccid	4 leaves wilting; 2 leaves showing unilateral wilting	7 leaves wilting; 2 leaves showing unilateral wilting
5 (9 leaves)	—	—	—	—	2 leaves showing unilateral wilting	1 leaf wilting; 2 leaves showing unilateral wilting
7 (11 leaves)	—	—	—	2 leaflets on 1 leaf flaccid	2 leaves wilting unilaterally	2 leaves wilting; 2 leaves wilting unilaterally

2, and 3. During the first two days after inoculation the transpiration rate of the four inoculated plants increased relative to the controls but when tested statistically using the "t" test this increase was not found to be significant. From the fourth

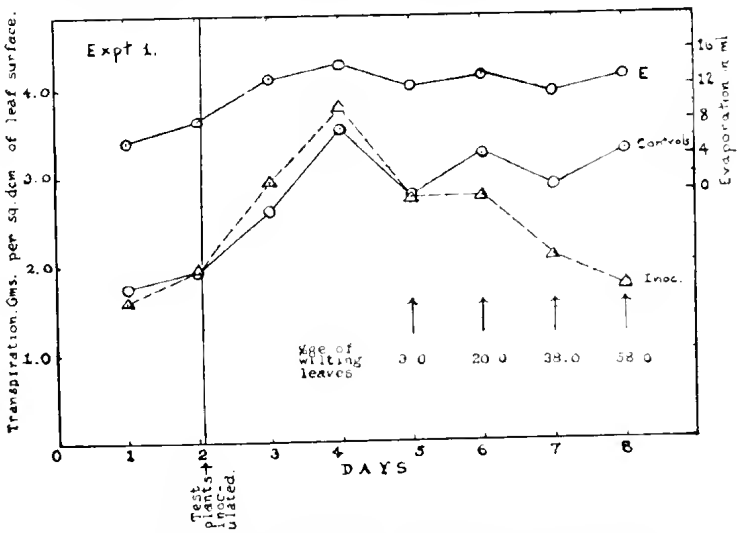

FIG. 1.—The march of transpiration in relation to the march of invasion when invasion is rapid. Expt. 1. Mean values for four control and four inoculated plants.

day after inoculation a continuous decrease in the rate of the inoculated plants occurred but the difference barely became significant as determined by the "t" test, even by the seventh day after inoculation when the experiment was terminated. In this connexion it may be stated that in examining statistically the averaged results for the four test and control plants, a complicating factor is introduced by the differential speed of bacterial invasion in each inoculated plant. Thus in test plants 1 and 3, by the sixth day after inoculation most leaves were wilting and transpiration was reduced greatly below that of the controls (see text fig. 2). In test plants 5 and 7 on the other hand symptoms

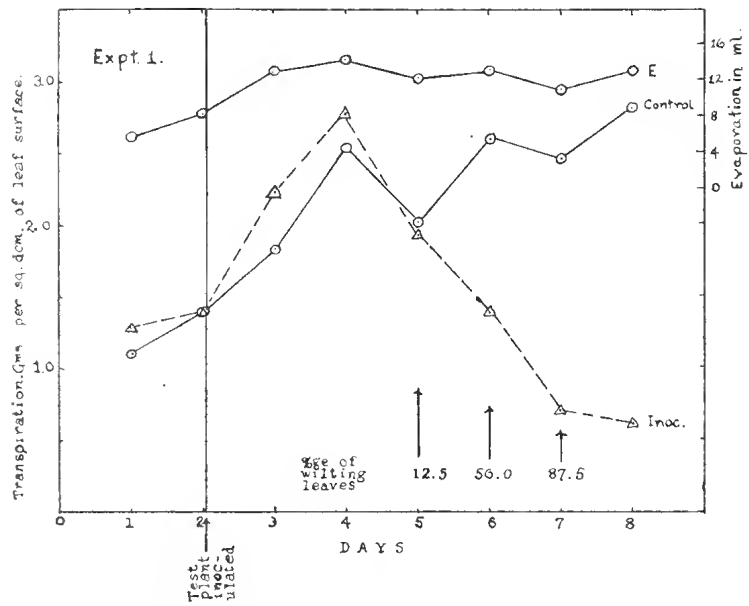

FIG. 2.— The march of transpiration in relation to the march of invasion when invasion is rapid. Expt. 1. Test plant 1 and Control.

developed later and reduction in transpiration was only commencing to show by the sixth day. The experiment would have had to be continued to the tenth or twelfth day for them to reach a comparable stage of wilting to that of test plants 1 and 3. This time lag reduces the differences between test plant and control series when averaged results from day to day are taken and examined by the "t" test. The results in individual cases in this experiment, and in others to be described, leave no doubt about the actual depression of the transpiration rate of the infected plants relative to the controls.

An interesting point is that little difference between the transpiration rates of the inoculated and control plants developed

until one or two leaves (out of a total of 7 to 9 on each plant) were showing some degree of wilting. This result suggested that in the early stages of wilting, increasing invasion of vessels was accompanied by increased conduction in vessels still free, while non-affected leaves connected with these transpired an increased volume of water. Other evidence on this point is presented later.

When the mean cumulative water loss by transpiration from test plants 1 and 3 and from their controls is considered (text fig. 3), it is seen that a definite reduction in the total volume of

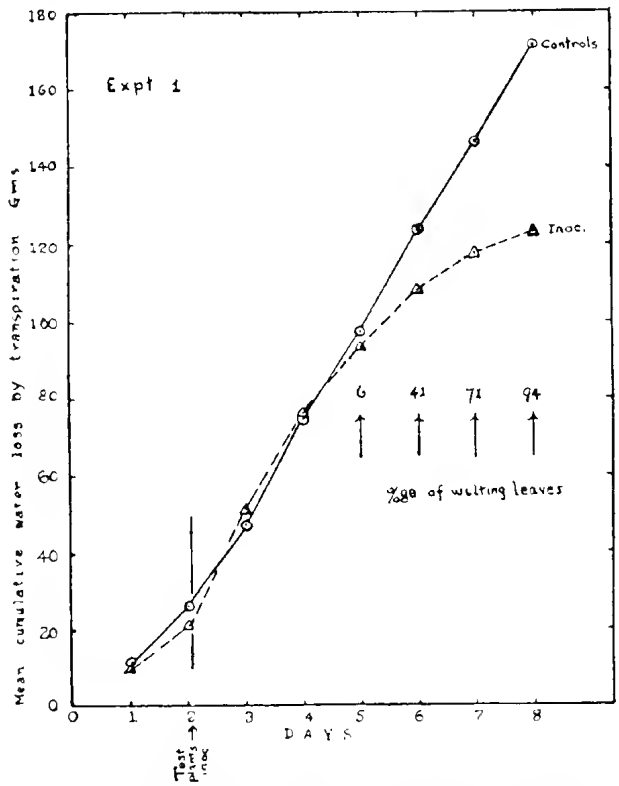

FIG. 3.—Comparison of the mean cumulative transpiration losses from two healthy and two inoculated tomato plants. Expt. 1.

water transpired relative to the controls is becoming apparent by the fourth day after inoculation when 41 per cent. of the leaves were showing degrees of wilting. The gradual nature of the interference with transpiration is clearly shown in this graph.

In a second experiment in which a set of four inoculated and four healthy plants were used, results compatible with Experiment 1 were obtained.

(*b*) Transpiration Relations when Invasion is Moderately Rapid.

Experiment 3.—Plants were placed for the period of the experiment under dense shade conditions in a glasshouse with the object of reducing the speed of invasion and favouring the induction of epinasty. Temperature remained optimum for invasion. Epinastic response occurred in a high percentage of leaves of all the infected plants and it was found in this experiment that their transpiration rate began to show reduction one day after the development of the epinasty. This reduction became more pronounced each succeeding day that the condition persisted. Owing to the low transpiration rate under the shade conditions of the experiment, leaves remained turgid, though reflexed, until a high degree of invasion was reached.

(*c*) Transpiration Relations when Invasion is Slow.

Experiment 4.—This experiment was carried out in autumn and early winter and was designed to give information on the effect of slow invasion on transpiration. Temperature and light conditions were such as to allow fairly rapid growth of the test plants, but were sub-optimal for bacterial growth. Ten tomato plants were selected, grouped in pairs of closely similar size and their daily transpiration losses over a ten-day standardization period determined. One plant of each pair was then prick inoculated with *Bacterium solanacearum* in a vascular bundle near soil level. Transpiration losses of each grouped pair and the progress of invasion as indicated by epinastic response of leaves (Pl. XI., fig. 1), unilateral wilting and bilateral wilting of leaves were recorded during 30 days when the experiment was terminated. Results are expressed in Table II. and text figs. 4 and 5. For convenience of presentation the mean transpiration losses for each set of plants were grouped in five-day runs. Depression of the rate from infected plants relative to the controls began to be apparent by the tenth day after inoculation. This difference increased as invasion continued up to the close of the experiment when a high percentage of wilting leaves was showing in the infected plants. At the close of the experiment the difference in rates between inoculated and healthy plants was significant at the 1 per cent. level, using the "t" test. If one considers any given pair of the inoculated-control series a clearer picture is given of the effect of slow invasion on transpiration. Results for test plant 3 and its control (see Table II.) are given in text fig. 5. During the ten-day standardization period there is close agreement between the volumes of water transpired by each plant and this relation continues for a further twelve days after test plant 3 had been inoculated. By this time symptoms were commencing to develop. It was not, however, until four out of the eight leaves on the plant were showing epinastic response

that its transpiration began to drop below that of its control. It is to be noted that the water loss from the infected plant remained relatively high up to the close of the experiment, the loss from the healthy plant not being overwhelmingly greater except on days when the climatic conditions favoured high transpiration. The maintenance of this relatively high rate is believed, on the basis of eosin and section tests, to be due to the failure of the bacteria to penetrate in sufficient numbers into the freshly developing xylem vessels in the plant, so that a conducting channel between the roots and the apical leaves was kept open.

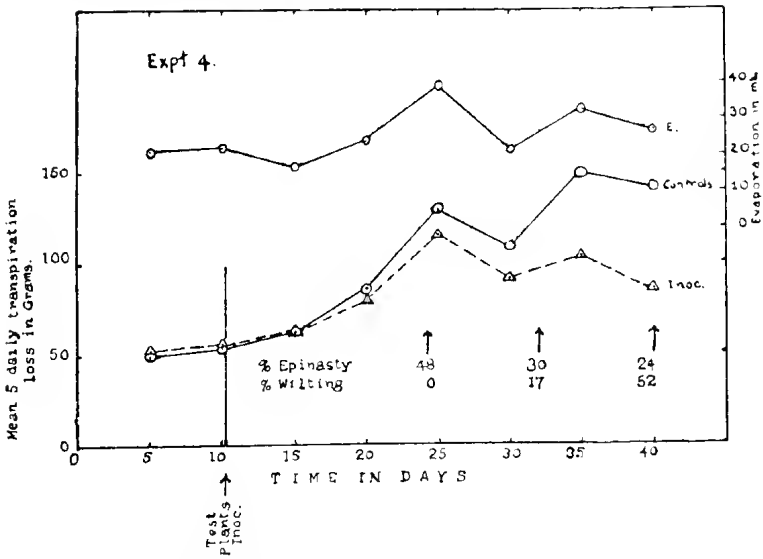

FIG. 4.—The march of transpiration in relation to the march of invasion when invasion is slow. Comparison of the five daily average transpiration from healthy and inoculated tomato plants. Expt. 4.

Results of this experiment parallel those where invasion was rapid, differing only in the prolongation of the epinasty phase and in the strong development of secondary tissues. The prolongation of the epinastic phase in the presence of increasing numbers of bacteria has an important bearing on the "bacterial" theory of wilting and will be referred to later.

To summarize the results obtained from the four experiments in this section we may say that each has shown that under varied environmental conditions—(*a*) the march of transpiration in infected plants runs parallel with that in control plants for one to two days after the appearance of well defined symptoms in the former. The depression in the transpiration rate which then becomes evident does not appear to be directly conditioned by available leaf area; (*b*) the reduction of the transpiration rate in infected plants under all conditions of invasion is a gradual process and no sudden disturbance of this function occurs.

TABLE II.—PROGRESS OF INVASION AS INDICATED BY SYMPTOMS. EXPT. 4.

EXPT. PLANT.	TIME IN DAYS AFTER INOCULATION.					
	12	15	20	22	25	29
1 (9 leaves)	—	4 leaves showing epinasty	One leaflet on 1 epinastic leaf wilting, otherwise no change	5 leaves showing epinasty; leaflets on 2 epinastic leaves wilting	3 epinastic leaves showing unilateral wilting; 2 unchanged	4 leaves severely wilted; 3 leaves wilting; 1 epinastic; 1 normal
2 (9 leaves)	1 leaf showing epinasty	5 leaves showing epinasty	One leaflet on 1 epinastic leaf wilting, otherwise no change	Unilateral wilting in 3 epinastic leaves	No change	No change; 5 leaves normal
3 (8 leaves)	1 leaf showing epinasty	4 leaves showing epinasty	Unilateral wilting in 1 epinastic leaf; rest unchanged	Unilateral wilting in 3 epinastic leaves	No change	3 leaves wilted 3 epinastic; 2 normal
4 (10 leaves)	—	3 leaves showing epinasty	No change in epinastic leaf; 1 leaf wilting unilaterally	4 leaves showing epinasty; 1 leaf wilting unilaterally	No change	3 leaves wilted; 1 unilaterally wilted; 4 epinastic, 2 normal
5 (10 leaves)	1 leaf showing epinasty	6 leaves showing epinasty	No change	Unilateral wilting in 3 epinastic leaves	Unilateral wilting in 5 epinastic leaves	8 leaves wilting; 1 flaccid; 1 normal

COMPARISON OF HOURLY TRANSPIRATION RATES OF CONTROL AND INFECTED PLANTS AT THE INCIPIENT WILTING STAGE.

During the two days in which wilt symptoms were developing in test plants 1 and 3 of Experiment 1, a comparison of their hourly transpiration rates with those of their controls was made (text fig. 6). Both inoculated plants appeared fresh and normal at 8 a.m. when the hourly observations were commenced. By 12 noon two leaves of test plant 1 were wilting and one was flaccid, while in test plant 3 one leaf was wilting and two leaves were showing commencement of unilateral wilting. By 2 p.m. the picture was much as set out in Table 1, column 4. Turning to the transpiration record (text fig. 6) it may be observed that on the first day the transpiration rates of the control and inoculated plants rose by almost equal increments of rate until 11 a.m. During the period 11 a.m. to 1 p.m. the controls transpired at a considerably higher rate. It was during this period that flaccidity was becoming evident in certain leaves of the inoculated plants. Between 1 and 2 p.m. the transpiration of inoculated plants showed a greater increase relative to the controls, but between 2 and 3 p.m. with evaporation still increasing, the inoculated plants showed a decrease of 27 per cent. relative to the preceding hour's rate, while the transpiration rate of the

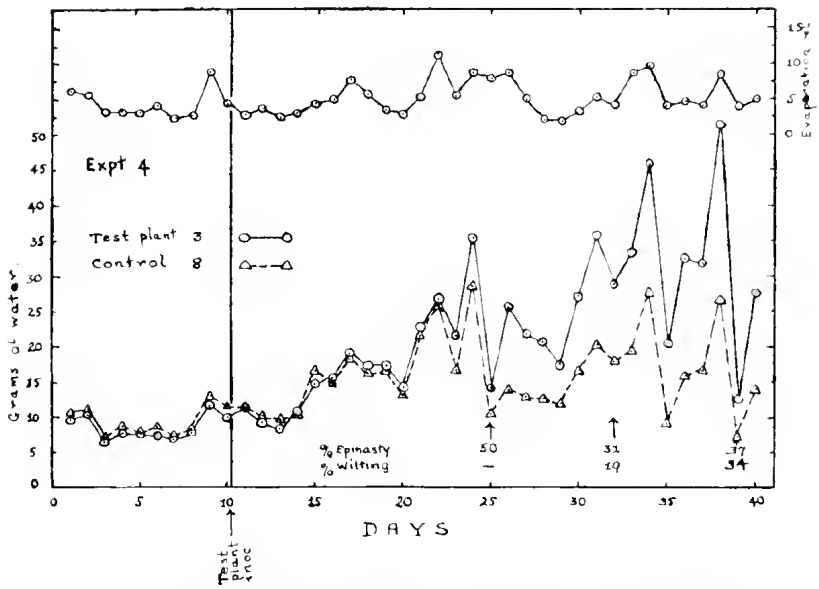

FIG. 5.—Comparison of transpiration from a healthy and an inoculated plant under conditions of slow invasion. Expt. 4. Test plant 3 and Control.

controls continued to rise. From 3 to 4 p.m. the rates of transpiration in both sets were decreasing, but the relative decrease was 10 per cent. greater in the controls. In the record for the following day the only noteworthy feature was a repetition of the rate increase of the infected plants relative to the controls (22 per cent. : 2.5 per cent.) during the 1 to 2 p.m. period. A possible explanation of these effects is that with the commencement

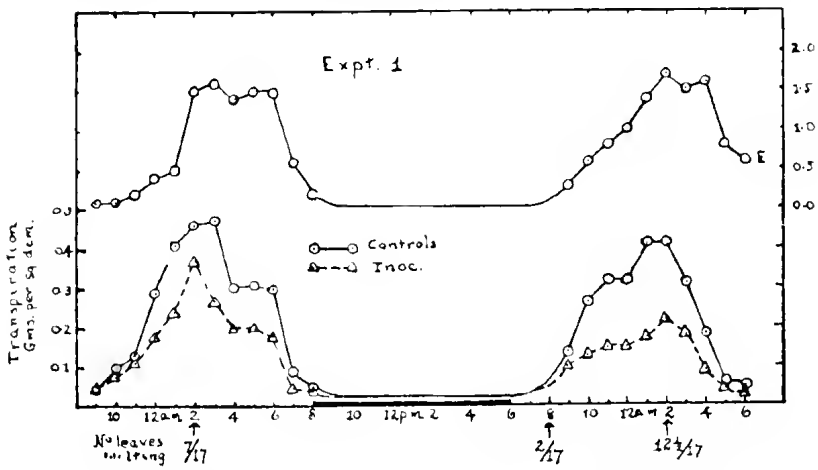

FIG. 6.—The daily march of transpiration in healthy and inoculated plants when bacterial wilting is just commencing. Mean values for Test plants 1 and 3 and their Controls. Expt. 1.

of bacterial wilting the stomata open more widely and the transpiration rate rises steeply for a short time after the manner described by Knight (1922) for plants wilting from lack of water. It is suggested that the subsequent earlier fall in the transpiration rate of infected plants may be due to the fact that a transpiration-limiting water content of the mesophyll cells is reached more rapidly in the infected plants than in the controls owing to the operation of two factors:—(*a*) The more widely open stomata during the preceding phase, and (*b*) the interference with the conduction of water to the leaves. Further investigation of these effects is being made with special reference to stomatal movements during the wilting phase.

The graph also shows that both in healthy and infected plants the hourly march of transpiration follows the normal course observed for many herbaceous plant types. In the healthy plants it is evident that the rate of transpiration increased more rapidly than the rate of evaporation, as registered by the atmometer, until a maximum was reached and the later increase in the exaporating power of the air was not reflected in the rate of water loss. The curves also show that transpiration increases rapidly during the daylight hours when the stomata are open and falls very low during the night hours when the stomata are closed. The overnight restoration of turgidity in wilting leaflets of infected plants is due to this decrease in transpiration.

Observations on Temporary Overnight Recovery of Turgidity in Flaccid Leaves.

During the course of the above experiments it was observed that leaflets of plants which become flaccid or wilted during the day often recovered their turgidity during the night. This recovery from flaccidity after a second day was frequently repeated during a second night, but usually by the third day the wilting became irreversible. Typical examples of this temporary recovery in infected plants are recorded in Table III. This recovery is of course due to the fact that the water content of the flaccid or wilted leaves builds up overnight while transpiration is reduced, but the effect is important in relation to certain theories advanced on the cause of bacterial wilting and the bearing of these observations on this wilting effect will be considered in Section VII.

IV. Comparison of the Rates of Transpiration from Companion Leaflets during Epinasty.

The epinastic response of leaves of infected plants, which has been referred to in connexion with Experiments 1 to 4, has been shown in an earlier paper (Grieve, 1939) to be conditioned by the path of invasion and generally to be associated with the

presence of bacteria at the base of the petiole. Depending on the speed of invasion, leaf epinasty is followed sooner or later by unilateral wilting of leaflets. Data presented in Section III. showed that transpiration began to decline one or more days after the development of epinasty and usually not until one or two

TABLE III.—OBSERVATIONS OF TEMPORARY OVERNIGHT RECOVERY OF TURGIDITY IN WILTING LEAVES OF INOCULATED PLANTS. DATA FROM EXPT. 3. LETTERS DENOTE LEAVES; *a* = LOWEST ON STEM.

		Days after Inoculation.			
		4	5	6	7
Test Plant No. 3. (8 leaves)	9 a.m.	Leaves *b*, *c* and *d* showing epinasty	Leaflets of *d* turgid	All leaves turgid	Leaves *d* and *e* turgid, leaf *g* unilaterally flaccid, leaf *b* unilaterally wilted
	11 a.m.	No change	Unilateral wilting in leaf *d*	Unilateral wilt-developing in leaves *b*, *d* and *g*	
	1 p.m.	Unilateral wilting in leaf *d*	No change	Unilateral wilt in leaves *b*, *d*, *e* and *g*	
	3–5 p.m.	No change	Unilateral wilting in leaves *b*, *d*, and *g*.	No change	Leaves *b* and *d* wilting bilaterally; leaves *e* and *g* unilaterally
	7 p.m.	Leaflets of *d* almost turgid	Leaflets of *d* almost turgid; leaflets of *b* and *g* still flaccid	No indication of recovery	No recovery
Test Plant No. 4. (9 leaves)	9 a.m.	Leaf *b* showing epinasty	No change from preceding day	All leaves turgid	Leaves turgid except *b* which remained flaccid
	3 p.m.	No change	Unilateral wilting commencing in leaves *b*, *e* and *g*	Unilateral wilting in leaves *b*, *e* and *g*	Leaves *b* and *e* wilting bilaterally; leaves *c* and *d* showing epinasty, while *f* and *g* show unilateral wilting
	7 p.m.	No change	All leaves recovered turgidity	No change	No change

leaves of a plant were wilting. It therefore appeared desirable to compare transpiration rate in companion leaflets of leaves showing epinasty or unilateral wilting and to relate the results obtained to transpiration relations discussed in the preceding section. At the outset, determinations were made on companion leaflets of healthy tomato and potato plants in order to find the degree of variation in transpiration rate between such leaflets.

Experiments on such companion leaflets using both the "three colour strip" method and the torsion balance method showed that the differences in rate between them were comparatively small (Table IV.). Determinations were next made on companion leaflets of leaves showing epinasty. The results (Table IV.) were examined statistically by the "t" test and showed that at the 1 per cent. level there was a significantly lower transpiration rate from one companion leaflet of a pair in plants showing leaf epinasty. Sections and eosin test showed the side with the reduced rate to be the invaded side. These experiments made it plain that some increase in transpiration rate must have occurred either in other leaves on the plant or in non-affected companion leaflets in a leaf showing epinasty, to account for the maintenance of transpiration rate which has been recorded in Expts. 1 to 3. It was not found practicable, however, to ascertain by the above methods whether part of this compensatory increase took place in the non-invaded side.

TABLE IV.—COMPARISON OF THE RATES OF WATER LOSS FROM COMPANION LEAFLETS (A, B) OF HEALTHY PLANTS AND FROM COMPANION LEAFLETS OF INFECTED PLANTS SHOWING LEAF EPINASTY. (IN INFECTED PLANTS A = INVADED SIDE.)

(*a*) *Torsion Balance Experiments.*
Water loss in mgms. per sq. cm. per hour.

Tomato.				Potato.			
Healthy.		Infected.		Healthy.		Infected.	
1A ..	0·56	1A	0·22	1A	1·01	1A ..	0·25
1B ..	0·49	1B	0·80	1B	0·96	1B ..	0·59
2A ..	0·40	2A	0·48	2A	0·83	2A ..	0·29
2B ..	0·39	2B	0·47	2B	0·83	2B ..	0·41
3A ..	0·30	3A	0·21	3A	1·08	3A ..	0·96
3B ..	0·24	3B	0·58	3B	1·08	3B ..	0·86
4A ..	0·41	4A	0·36	4A	0·28	4A ..	1·84
4B ..	0·55	4B	0·69	4B	0·31	4B ..	2·23
5A ..	1·26	5A	0·37	5A	0·47	5A ..	0·99
5B ..	1·14	5B	0·53	5B	0·38	5B ..	1·09
6A ..	1·60	6A	0·33	6A	0·25	6A ..	0·15
6B ..	1·60	6B	0·50	6B	0·23	6B ..	0·40
7A ..	0·17	7A	0·17	7A	0·25	7A ..	0·12
7B ..	0·18	7B	0·82	7B	0·35	7B ..	0·26
8A ..	1·78	8A	1·12	8A	0·27	8A ..	0·72
8B ..	1·77	8B	1·00	8B	0·26	8B ..	0·58
9A ..	0·81	9A	0·40	9A	0·11	9A ..	1·41
9B ..	0·69	9B	0·63	9B	0·13	9B ..	2·90
10A ..	0·31	10A	0·20	10A	0·25	10A ..	0·17
10B ..	0·23	10B	0·30	10B	0·23	10B ..	0·30

TABLE IV.—*continued.*
(*b*) *Cobalt chloride method.*
POTATO.

Healthy.				Infected.			
1A	40	seconds	1A	150	seconds	6A	180	seconds
1B	40	,,	1B	55	,,	6B	60	,,
2A	60	,,	2A	180	,,	7A	115	,,
2B	55	,,	2B	55	,,	7B	30	,,
3A	45	,,	3A	105	,,	8A	145	,,
3B	40	,,	3B	47	,,	8B	117	,,
4A	160	,,	4A	90	,,	9A	210	,,
4B	167	,,	4B	30	,,	9B	175	,,
5A	63	,,	5A	150	,,	10A	145	,,
5B	60	,,	5B	30	,,	10B	60	,,

V. The Effect of Invasion on Transpiration/Absorption Relations.

The wilting effect has so far been examined only in relation to water loss. Since theories of wilting in relation to bacterial invasion have postulated a breakdown of the absorption mechanism it was necessary to ascertain the effect of invasion on water uptake. In the following experiments absorption and also transpiration rates were recorded using potometer types A and B described under Methods. Initial experiments dealt with the relation between the rate of absorption and of transpiration in healthy tomato plants. The problem of water balance has received attention from various workers. Thus Montfort (1922) using the potometer, investigated the relationships between transpiration and absorption in *Zea mays* and *Impatiens parviflora* grown in Knop's solution and on transfer to peat and bog water. He found the transpiratory quotient (T/A) in Knop's solution and in peat and bog water to be generally greater than unity. Lachenmeier (1932) on the contrary found for *Veronica beccabunga* and *Myosotis palustris* that absorption exceeded transpiration both in light (artificial) and dark, or T/A was less than unity. Kramer (1937) recorded for sunflower plants growing in nutrient solution, that transpiration frequently exceeded absorption during the day, but that the positions were reversed during the night. The result of a typical experiment with healthy tomato plants is shown in text fig. 7. It is seen that under the conditions of these experiments in a warm glasshouse, transpiration generally exceeds absorption during the day while absorption is always greater than transpiration during the night. These results are in closest accord with those of Kramer who also worked under glasshouse conditions. It may be noted here, however, that in later experiments carried out under artificial light, results approximating to Lachenmeier's were obtained (see Section VI.). In the above experiments readings and weighings were taken at 9 a.m. and at 5 p.m. giving the comparison between absorption and

transpiration during the day and night periods, but for the longer experiments now to be described, in which the march of these two functions was followed in connexion with invasion, values were recorded for 24 hour periods, readings being taken at 9 a.m. each day. Each plant served as its own control, 24 hourly readings of both water uptake and water loss being taken for some days before inoculation and continued until epinasty and wilting effects were visible after inoculation. Root and apical stem inoculations were practised in different experiments in order to differentiate between the effect on absorption of the presence or local absence of bacteria.

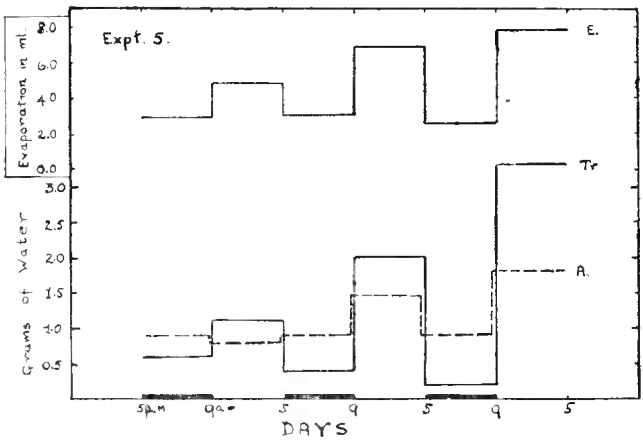

FIG. 7.—Rates of absorption and transpiration in healthy tomato plants during the day and night. Expt. 5.

(*a*) *Root Inoculation:*—Typical results are expressed in text figs. 8 and 9. No record of evaporation was kept for these experiments. The temperature record however, showed little variation and it has been observed in other experiments where both evaporation and temperature records were kept, that the curves followed roughly a parallel course. Consequently the falling transpiration and absorption rates shown in the later stages of the experiments were not due to changing environmental conditions but to the effect of the disease. Study of the text figures shows that there is no sudden interference with the absorption of water but that there is a gradual decrease in rate as the disease progresses. The plants were sectioned at various root and stem levels at the close of the experiments after being tested for eosin uptake through cut root tips. Examination then showed that the rate of absorption in the final stages was much higher than what might have been expected having regard to the number of vessels not conducting eosin. Thus in Experiment 9 (text fig. 8) for example, the absorption was 0.50 gms. over

24 hours (50 per cent. of its mean value up to inoculation) at a time when by eosin test it was shown that more than three-quarters of the total number of vessels of the main root were unable to conduct water. Similarly, conduction of water through the stem as judged by transpiration, was high in relation to the number of vessels still able to conduct as shown by eosin test. These observations link up with those of Section III.

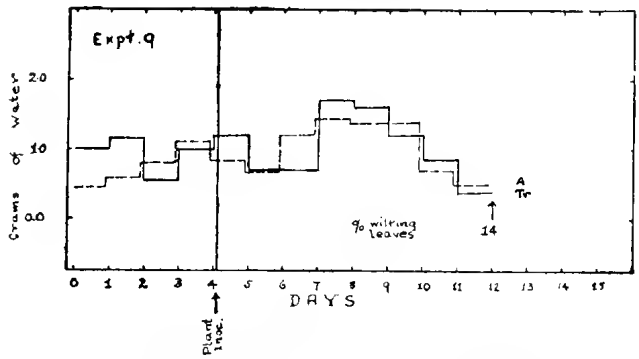

FIG. 8.—The effect of invasion by *B. solanacearum* on the transpiration and absorption of a tomato plant. Plant inoculated at base of stem. Expt. 9.

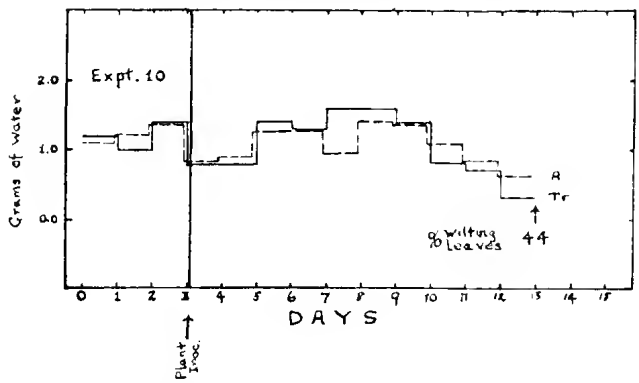

FIG. 9.—The effect of invasion by *B. solanacearum* on the transpiration and absorption of a tomato plant. Plant inoculated at base of stem. Expt. 10.

(*b*) *Apical Inoculation:*—This type of experiment was designed to determine whether any toxin or toxic substance produced by bacterial action could pass down to the roots and interfere with the absorption of water. A potato plant was used in one experiment, the inoculation point being high up on the stem. The experiment was carried on for four days by which time epinastic response but no wilting was showing in three apical leaves. The experiment was then stopped and an eosin and sectional analysis of the plant showed that the bacteria had grown

back down the vessels to the base of the stem but had not reached the roots. Just below the point where bacteria were present a certain amount of localised gum formation had occurred in and around vessels. Examination of the absorption rate (text fig. 10) shows that no depressant effect was exercised on the absorptive power of the roots by the bacteria growing back through the stem vessels. The results of this and other apical inoculation experiments taken in conjunction with the results for root inoculation experiments described earlier, indicate that the cause of wilting in tomato and potato plants is other than protoplasmic intoxication of root cells leading to reduced osmotic pressure and decreased absorption as was suggested by Hutchinson (1913).

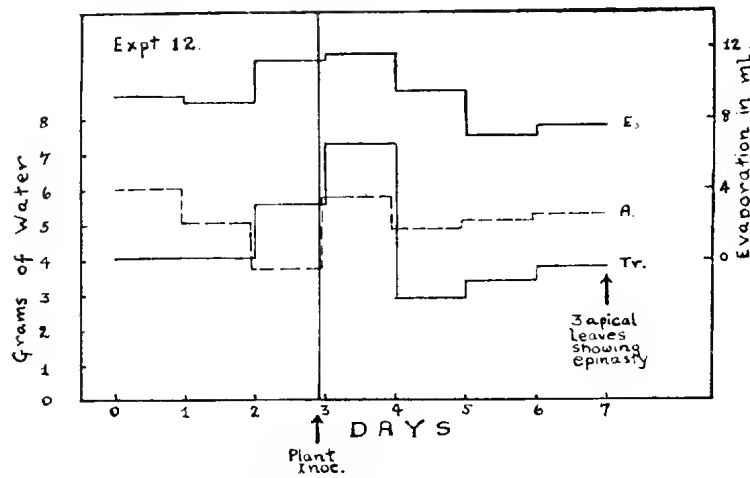

FIG. 10.—The effect of apical stem inoculation by *B. solanacearum* on transpiration and absorption in a potato plant. Expt. 12.

VI. The Effect of Artificially Reducing Leaf Area on Transpiration/Absorption Relations.

Results presented in Section III. indicated the development of a compensatory higher transpiration rate from unaffected leaves on infected plants to offset the reduction in rate in wilting leaves. To find whether this effect was the normal reaction of healthy plants on the reduction of their available leaf area the following experiments were performed. Transpiration/absorption rates in healthy tomato plants were determined using suitable potometers and then half or whole leaves were vaselined and the effect of this reduction in effective leaf area on the transpiration rate determined. Flask type potometers were used and the work was carried out in an insulated room, the illumination being provided by a 500 watt lamp. The tomato plants used were between five to seven inches in height, having six to eight well-expanded leaves. They had been grown in containers filled with washed sand and

watered with Shive's solution. After setting up in the potometer, using the procedure described under Methods, the plant was left for several hours, usually overnight, in the insulated room before an experiment was commenced. Further details of experimental technique with the small flask potometers may be given. The total weight of the potometer, nutrient solution and plant was approximately 180 grams. The balance used could carry up to 600 grams load and was sensitive to 8 mgms. The absorption was read off on a millimetre scale pasted along the absorption tube, and, after a correction for volume changes due to slight unavoidable rises in temperature had been applied, could be recorded in grams as the absorption tube in each potometer was carefully calibrated, using mercury. Experiments were first carried out to ascertain the normal absorption/transpiration relations in tomato plants under the conditions of these experiments. It was found that absorption tended to exceed transpiration slightly both in light and darkness. These results agree with those obtained by Lachenmeier for *Veronica beccabunga* and *Myosotis palustris* under similar experimental conditions. They differ from the results obtained under glasshouse conditions (Section V.) where absorption was found mainly to exceed transpiration only during the night. Absorption/transpiration values were next obtained at half-hourly intervals for a period of two to three hours, after which one half leaf or a complete leaf was vaselined on both surfaces. After vaselining a leaf in any experiment the plant was left for an hour before readings were resumed. Typical results are presented in text figs. 11 and 12. Vaselining of one leaf (fifth from base—nine leaves on plant) in Expt. 17 (text fig. 11) reduced the total leaf area by 18.2 per cent. and yet no reduction in the rate

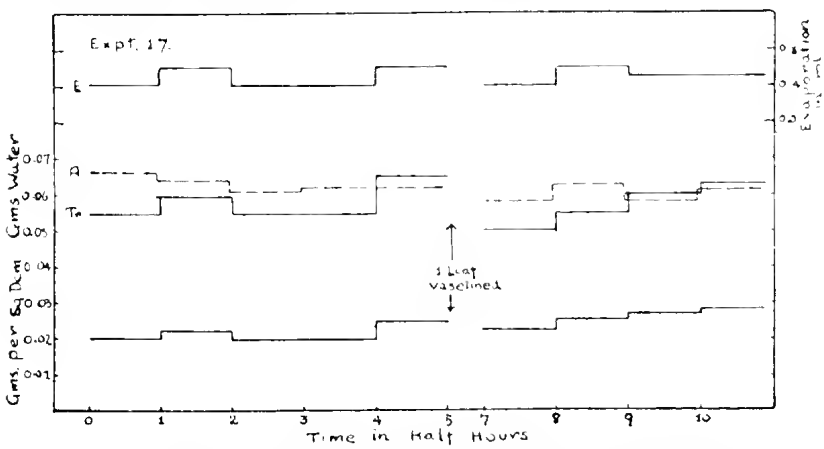

FIG. 11. Effect of vaselining one leaf on transpiration and absorption in tomato. Total number of leaves on the experimental plant was nine, and the fifth leaf from the base was vaselined. Original leaf area was 2.68 sq. dcm. and 2.19 sq. dcm. after one leaf was vaselined. Expt. 17.

occurred. In another experiment (No. 27) where one leaf (fourth from base—eight leaves on plant) was vaselined the reduction in leaf area was 28 per cent. and again no reduction in the rate of transpiration occurred. Text fig. 12 shows results obtained in two experiments when two and three half leaves respectively (cf., unilateral wilting in infected plants) were vaselined. The rate of transpiration under constant environmental conditions is more than maintained despite the reduction in leaf area. These results confirm the observations arising out of the

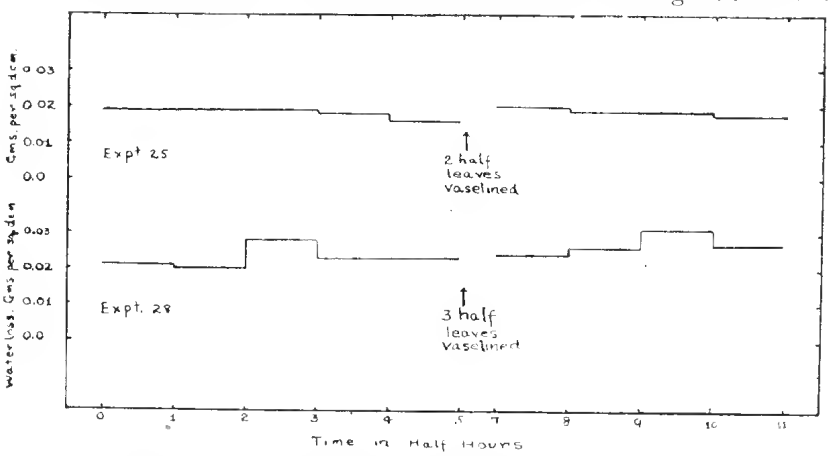

Fig. 12.—Effect of vaselining half leaves on the rate of transpiration. Expt. 25. Total number of leaves on the tomato plant was nine and half leaves of the 4th and 5th from the base were vaselined. Original leaf area was 3.66 sq. dcm.; residual area 2.89 sq. dcm. Expt. 28. Number of leaves six; half leaves of 2nd, 3rd and 4th from base vaselined. Original leaf area = 2.79 sq. dcm.; residual leaf area 1.89 sq. dcm.

study of transpiration rate in relation to bacterial invasion and wilting, in that they demonstrate that the rate of water loss may be maintained despite the reduction of available leaf area ranging up to 33 per cent. in the experiments so far reported. Since the experiments were carried out under controlled conditions of temperature and light it is clear that the supply of water to and the transpiration of water from the remaining leaves must have been increased. Reference to this effect occurs in Maximov's book *The Plant in Relation to Water* (p. 121, 2nd imp., 1935). He states "It has frequently been observed that if a portion of a plant is divided into separate pieces the intensity of transpiration is markedly increased. Famintsin (1883) in his book on the metabolism of plants cites the following experiment performed by his pupil Krutizky. A hawthorn shoot with eight leaves transpired 8 gm. of water a day; one with five leaves 5.2 gm.; and a shoot with only one leaf 4.9 gm. One the basis of the amount transpired in the third case, the first shoot should have transpired 39.2 gm. instead of 8 gm., and the second 24.5 gm. instead of 5.2 gm. This can only be explained by supposing that as leaves are successively removed from a shoot, the supply of water to the remaining still attached leaves is increased."

The chain of events involved in the increased supply of water to unaffected leaves in plants in which one or two leaves had been vaselined, may be visualized as follows, assuming the plant to be growing under conditions of constant light and temperature and to be well supplied with water. In the diagram (text fig. 13) A and B represent cells of two leaves which are served by vascular bundles which join at D, and C represents a cell in contact with the xylem of the root. We know that when a plant is transpiring

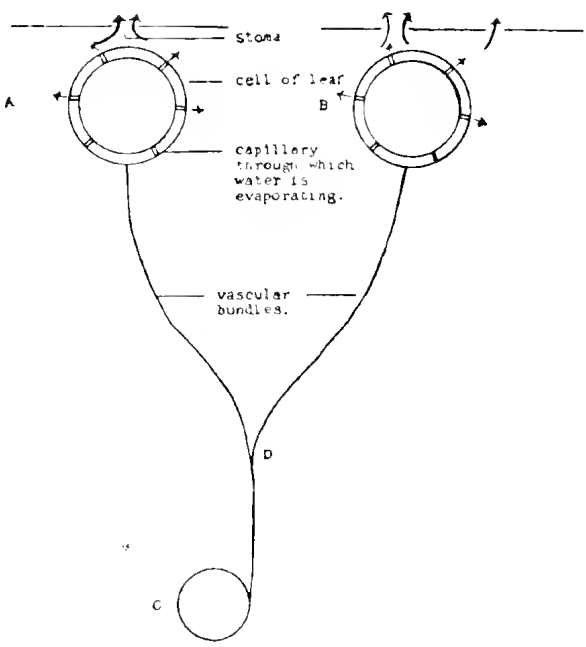

FIG. 13. Diagram to illustrate processes involved in increasing transpiration intensity with decreasing leaf area. See text.

a gradient of suction pressures is developed in the cells from the leaves down to the roots. The suction pressures developed at A and B may be assumed to be approximately equal and will be higher than the suction pressure at the point of water supply C. Consequently water will be drawn up through the stem vessels and approximately equal volumes will travel to cells A and B. The two leaves will be transpiring at rates proportional to the saturation deficit. Owing to the competition between them for water from C, however, the minute capillaries in the walls of the mesophyll cells A and B will not be completely filled with water and the outer layers of the cell walls will tend to dry. Under these conditions evaporation will be reduced. Now, if one leaf A be vaselined, exaporation is prevented and its cells show increasing turgidity. Applying the equation $S = P-T$, when S = suction

pressure, P = osmotic pressure, and T = wall pressure, it is clear that with increasing turgidity the suction pressure of cell A falls and finally the value of this approximates to the suction pressure of the water-supplying cell C, and no further water is drawn to cell A. Owing to the decreasing water demand from A, the suction pressure of cell C also falls as it becomes more turgid. This leads to the establishment of a greater suction pressure gradient between leaf cell B and the cell C. The net result is that a greater volume of water than before is drawn to cell B. As this cell shows increasing turgidity owing to the increased water supply, the water menisci in the minute capillaries in the walls of the mesophyll cells move outwards as the capillaries become filled with water, and finally there may even be liquid water present on the outside of the cell walls. Evaporation would then increase, occurring as from a free water surface in a vessel filled to the brim, and the gradient of suction pressure between B and C would be maintained in sufficient degree to cause the more rapid flow of water to B.

In infected plants where the bacteria are gradually filling vessels leading to one of two leaves, a somewhat similar chain of events may be postulated. The suction pressures of the cells of the leaves below which bacterial blocking is occurring, would of course rise, as less water passes to them, but as this force cannot be transmitted down to the point of water supply, the net result is that an increasing volume of water passes to the free leaf as the osmotic mechanism described above comes into play.

VII. Discussion of Results and their Bearing on the Physiology of Bacterially Induced Wilting.

It has been demonstrated in the preceding experiments that there is a progressive interference with the transpiration and absorption in infected plants as wilting of leaves increases. It is necessary now to interpret the experimental results obtained more closely in terms of the actual cause or causes of the disturbance of the water relations of the invaded plant. The history of investigations bearing on this point may here be considered.

Historical Survey:—Hunger (1901), from his examination of infected tomato and tobacco stems, concluded that the wilt was caused by the plugging of the vessels by the bacteria. He stated further that tyloses were abundant in the vessels of diseased tomato plants and believed that these structures, which apparently were induced by parasitic attack, helped to prevent the upward transport of water to the leaves. Hutchinson (1913), in a paper on Rangpur Tobacco Wilt caused by *B. solanacearum* in India, discounted the hypothesis that wilting was due to parasitic plugging of the vessels, in the case, at least, of tobacco wilt. From his observations on the disease and from experiments that he carried out, he was led to attribute the wilting effect to the action

of secreted toxins from the parasite on the cell protoplasm. His evidence may be summarized as follows:—1. Bacteria are not present in sufficiently large numbers in the vessels of wilted plants to cause any serious interference with the water supply of the plants. 2. A healthy tobacco plant may be cut half through the stem without causing wilt even in the leaves immediately above the cut. 3. An alcohol precipitate from a bouillon culture when dissolved in sterile water and fed into the vascular system of a healthy plant caused wilt in the course of a few days; when boiled it had no effect. He believed that the real explanation of wilting in relation to failure of water supply was that in the earlier stages of the disease at least, toxins produced by the organism caused protoplasmic intoxication leading to lowered osmotic pressure in the root system. In the later stages of the disease the water supply would be further interfered with by the formation and accumulation of gum masses in the vessels. Van der Meer (1929), who has done the most detailed work on this subject, carried out a number of experiments to ascertain the cause of wilting in infected tomato and tobacco plants and concluded that no one factor was responsible. The abridged account she gives in English of the results of her investigations on this point reads as follows: -" In which way will the bacteria influence the water supply in a plant? Possibly the co-operation of the factors mentioned in the different theories, results in a deficit of water. These factors may be: (1) root damage, (2) substances secreted by the parasite in the vessels, upon which the plant reacts by gum-formation and discolouration of the vessel walls, (3) accumulation of bacteria here and there in the vessels ".

The present investigation into the cause of wilting in the case of tomato and potato plants invaded by *B. solanacearum* will be considered under the following headings:—(1) gum formation, (2) tylose formation, (3) toxin production, and (4) mechanical blocking.

(1) *Gum Formation:*—Observations were made on the presence or absence of gum in the test tomato and potato plants used in the experiments described earlier in this paper and the possibility examined of this substance being concerned. In no case did the amount of gum present in the stem and petiolar vessels suggest the possibility of mechanical interference. Gum formation was in fact of much rarer occurrence in the vessels than in the cells surrounding the bundle groups. Gum formation was also more commonly observed in cortical cells and in cells of the interfascicular cambium than in the vessels. Its occurrence here was surprisingly localised. One transverse section of a stem or root would show gum in the cells while the next serial section would fail to show it. Longitudinal sections showed that the gum formation in the vessels was of sporadic occurrence and not in amounts sufficient to cause blockage. Experimental evidence, particularly from the absorption experiments, indicated that such

gum as was present in cells and vessels of the stem and root did not affect the passage of water. In experiments where apical inoculation was practised, gum appeared in root vessels and cells ahead of the bacteria which were multiplying and growing downwards in the xylem, and yet no obvious interference with the absorption of water occurred at that stage. Again eosin passed rapidly up through vessels in, or around which, gum formation was evident, but in which no bacteria were present. Van der Meer (1929) gives no data on the occurrence of gum in infected tomato plants, but apparently bases her conclusion that gum formation is involved in interference with water supply on experiments in which cut tomato seedlings were placed in the filtrate of beef-broth cultures of *B. solanacearum*. Her observations are as follows:—"After 12 hours there was no wilting to be observed, but cross sections of the tomato stems from the bacterial filtrate showed that the walls of some vessels were discoloured yellow and that some vessels contained gum." The occurrence of gum in some vessels after such treatment is not surprising, but the critical point is that no wilting was observed, so that her conclusion is regarded as being invalid in the case of tomato plants. Similar experiments to those above have been made by the author (Grieve, 1939), and again no wilting has been observed in the presence of gum formation; consequently for this reason and for the more cogent reasons adduced above, it is concluded in the case of tomato and potato plants invaded by *B. solanacearum* that gum formation in cells and vessels is not causally concerned with the interference with the water relations of such infected plants. The strain of *B. solanacearum* used would not infect tobacco, so that no attempt could be made to confirm the conclusions of Hutchinson and Van der Meer for this plant. There is, however, some evidence that the degree of gum formation and possibly its blocking effect is dependent on the host plant. Thus in *Impatiens balsamina* large amounts of gum have been observed in the vessels and it is hoped later to investigate its importance here.

(2) *Tylose Formation:*—The procedure adopted in investigating the incidence of tyloses was to cut transverse and longitudinal sections of the stems and roots, wash out the bacteria from the invaded vessels and then examine for the presence of these structures. Tylose formation does occur, but in only one isolated case where one bundle of a potato plant showed four to five vessels with well developed tyloses was there any real possibility of interference with water movement. In the vast majority of plants examined, the tyloses were small structures just showing as minute protuberances in relation to the size of the vessel at the time of onset of the wilting phase. The conclusion reached is that in tomato and potato plants tylose formation was not causally related to wilting and the disturbance of the water relations of the plant.

(3) *Toxin Production:*—Hutchinson's theory that wilting is due to toxins causing protoplasmic intoxication leading to lowered osmotic pressure is considered to be untenable, as far as the plants worked with by the author are concerned since (*a*) no confirmation of the presence of a toxin has been obtained on repeating Hutchinson's type experiment (Grieve, 1939); (*b*) absorption rate is not reduced when the bacteria are growing back from the top of the stem after apical inoculation until they are present in great numbers. If a toxin were involved and Hutchinson's view was correct, wilting due to lowered absorption should have occurred before the bacteria actually were present in the roots; (*c*) flaccid or even wilted leaflets of invaded plants recover overnight in the early stages of invasion (see Table III.), and (*d*) wilted leaves on being cut off and placed in water recover their turgidity. Such recovery could not occur in the continuous presence of a toxin. The example given under (*d*) indicated that the wilting effect is due simply to a temporary shortage of water. During the day water is lost more rapidly from the affected leaves than it can be made good through the partially invaded vessels. During the night reduced transpiration allows of building up of the water content of such leaves. The conclusions given here apply to tomato and potato and not to tobacco plants, but it is of interest to observe that Van der Meer applied the same criterion of recovery from wilting in discussing the possible occurrence of a toxin in invaded tobacco plants. She writes "If *B. solanacearum* secreted substances which poisoned the parenchymatic cells of the leaves, in my opinion a limp leaf had to persevere in its condition, when the vessels were experimentally enabled to transport water. . . . This observation suggests, that the inability of the xylem in the stem to transport sufficient water to the leaves has caused wilting, and contradicts the explanation of Hutchinson that the wilting symptoms of slime-disease would have been caused by protoplasmic intoxication and decreased osmotic pressure." In view of the result of this experiment and of others in which she was unable to confirm Hutchinson's results it is surprising to find she is unwilling to abandon the concept of toxin action in tomato and tobacco plants.

(4) *Mechanical Blocking:*—A considerable body of evidence regarding the part played by the bacteria in causing wilting by mechanical blocking, has been accumulated during the course of experiments extending over several seasons. At the close of all experiments when infected plants were showing epinasty or wilting, the procedure was adopted of cutting off the tips of their main roots and placing them in a solution of eosin for half an hour. Thin hand sections were then cut at the bases of petioles and stems, and roots were either sectioned at various levels or subjected to the maceration methods described elsewhere (Grieve, 1936). The results of some of these observations are embodied

in Tables V. and VI. which give the section analysis in the case of test plants used in certain of the transpiration experiments reported earlier in this paper. The picture for test plants 1 and 3 of Expt. I (Table V.) is one of almost complete occlusion of vessels by the invading organism. The degree of bacterial blocking was not as great in test plants 5 and 7; the slower reduction of transpiration rate and the freshness of certain apical leaves in these plants at the close of the experiment reflects the lesser degree of blocking. The eosin and sectional analysis showed that some few vessels in the large vascular bundles escaped invasion and sufficient water was transported from the roots to the apical leaves to keep these turgid. Strong bleeding developed from the roots of these test plants and indicated that where mechanical blocking was not complete the absorbing

TABLE V. DISTRIBUTION OF BACTERIA AND THE DEGREE OF BACTERIAL BLOCKING AS DETERMINED BY SECTIONING AFTER EOSIN TRANSPORT TEST, EXPT. I, CORRELATE WITH TABLE I.

	Test Plant.			
	1.	3.	5.	7.
Base of leaves	*a* Vessels of all bundles completely blocked with bacteria *b* Vessels of all bundles completely blocked with bacteria *c* Vessels of all bundles completely blocked with bacteria *d* Vessels of all bundles completely blocked with bacteria *e* Vessels of all bundles completely blocked with bacteria *f* Vessels of all bundles completely blocked with bacteria *g* Vessels of all bundles completely blocked with bacteria *h* Slight invasion of one lateral bundle	*a* All bundles blocked *b* All bundles blocked *c* All bundles blocked *d* All bundles blocked *e* All bundles blocked *f* One lateral and the central bundle completely blocked. Only 2-3 vessels in other laterals blocked *g* All bundles blocked *h* Both laterals blocked; central bundle free *i* Slight invasion of all bundles	*a* Both laterals blocked; central free *b* Both laterals blocked; central free *c* Both laterals blocked; central free *d* All bundles completely blocked *e* Unilateral invasion *f* Heavy invasion, but eosin able to pass *g* Unilateral invasion *h* Unilateral invasion *i* Unilateral invasion	*a* Both laterals blocked; central free *b* Both laterals blocked; central free *c* All bundles blocked *d* Unilateral invasion *e* All bundles blocked *f* Bacteria present but not in blocking numbers *g* Heavy unilateral invasion *h* Slight bilateral invasion *i* Slight invasion *j* Slight invasion *k* Slight invasion
Stem	Section cut at level of *d* showed complete blocking of two large bundles and of three small bundles. In the third bundle only a few vessels showed eosin	Section at level of *e* showed two large bundles and the three small ones completely blocked. Sections at level of *e* and *h* showed same degree of blocking	Section at level of *d* showed eosin present in 5-6 vessels of each bundle, the rest being blocked	Section at *e* showed bacteria blocking all the earlier formed vessels. Vessels nearer the cambium showing eosin. Section at *j* showed bacteria in one large bundle
Root	Slight watery exudate. Heavy blocking of most vessels	Slight watery exudate. Bacteria present in blocking numbers in most vessels	Strong watery exudate from two bundles. Bacteria present but not in blocking numbers; one bundle completely blocked	Strong watery exudate. Bacteria present but not in blocking numbers

TABLE VI.—DEGREE OF BACTERIAL BLOCKING AS DETERMINED BY EOSIN TEST AND SECTIONING AT CLOSE OF TRANSPIRATION EXPT. 4.

Test Plant Number.	4.	8.	9.	10.
Leaves..	*a*, *b*, *c* All bundles blocked and considerable breakdown of xylem *d* Both laterals blocked; central free *e* One lateral and central bundle blocked; lighter invasion in other lateral *f* One lateral and central bundle blocked; lighter invasion in other lateral *g* One lateral and central blocked; eosin in other lateral *h* Eosin in all bundles Bacteria in vessels of one lateral *i* One lateral and central blocked *j* Central bundle only blocked, eosin in laterals	*a*, *b*, *c*, *d* All bundles blocked by bacteria *e* Both laterals and central bundles invaded, but eosin was able to pass *f* All bundles completely blocked *g* Half the vessels in one lateral blocked, Rest of vessels in this bundle, and vessels in other bundles passed eosin *h* Slight invasion of all bundles *i* One lateral heavily invaded; other lateral free of bacteria but no eosin passing due to blocking lower down in the stem	*a*, *b*, *c*, *d*, *e* Complete blocking of vessels *f* Only 2 3 vessels invaded in one lateral; all other vessels showing eosin *g* Both laterals and central blocked *h* One lateral blocked, other lateral free of bacteria and showing eosin *i* One lateral and central bundle blocked; other lateral only partially blocked *j*, *k* All bundles blocked *l*, *m* One lateral and central bundle blocked	*a*, *b*, *c*, *d*, *e* All bundles completely blocked *f* One lateral blocked *g* All bundles blocked *h* One lateral and the central bundle blocked *j*, *k*, *l*, *m* Fairly heavy invasion
Stem ..	Section at level of *d* showed one large bundle quite blocked. A second large bundle was heavily invaded and the third only slightly	Level of *d*. A few vessels of each bundle allowed passage of eosin, the rest being blocked by bacteria	Level of *g*. Eosin was present only in one large bundle, the others being blocked	Eosin passing in a few vessels of one large bundle at level of *f*
Root ..	Not recorded ..	Not recorded ..	Bacteria heavily invading vessels down to 2 inches below soil level	Bacteria filling approximately 50 per cent. of larger vessels

mechanism was not affected by the presence of bacteria or their metabolic products. An illustration of the degree of blocking commonly recorded when the statement "all bundles completely blocked" is made in the tables, may be seen in Pl. XI., fig. 3. The typical degree of blocking associated with epinastic response of leaves is illustrated in earlier papers (Grieve, 1936, 1939). The details given in the 1939 paper apply as well to the physiology of wilting although that aspect of interpretation was not there stressed. The data presented above is considered to provide conclusive evidence for the mechanical blocking theory in the case of tomato and potato plants.

It is of value here to consider results and interpretations of other workers. Van der Meer (1929), while not using the refinements of technique here employed in assessing the value of blocking, nevertheless made many careful observations. She

employed an eosin transport test followed by "barking" of the stem to observe the movement of eosin, and sectioning to determine the presence or absence of bacteria. Unfortunately her observations on the presence or absence of bacteria at the bases of leaves are limited to +, ++ or — signs, no clear indication of numbers present being given. Furthermore no information is contained in her tables on the occurrence of bacteria in the stem; consequently it is not possible to determine any relation between the bacteria in the vessels, the transport of eosin and the wilting of leaves in the tomato plants she used. Conclusions reached by Van der Meer, however, are as follows:—(*a*) Leaves can be turgid, although *B. solanacearum* be present in petiole and lamina, (*b*) flaccid leaves generally contain the parasite, in some cases, however, they are present only in small numbers, (*c*) sometimes loss of turgidity is not accompanied by the presence of *B. solanacearum*. Her interpretation of these results is that the invading organism did not cause the symptoms in a "direct way," which led her to include gum formation as a factor in the induction of wilting. It is not disputed that the conditions she lists do occur and in fact many similar conditions have been recorded, but all are readily explained without having to invoke any other factor than blocking by bacteria. By the stem sectioning or stem maceration analysis it has been demonstrated that the wilting of leaves in the presence of only small numbers of bacteria or no bacteria at all, is due to invasion lower down in the stem. In an earlier paper (Grieve, 1939) this point was stressed in relation to epinastic response of leaves. Turgidity of leaves in the presence of considerable though not "blocking" numbers of the invader is of common occurrence; epinasty of leaves which frequently precedes wilting, seldom occurs in the absence of the organism. Eosin conduction tests also showed that if even a few vessels remained uninvaded the dye passed upwards in them. It is considered that in the absence of complete section analyses of infected plant stems and roots, Van der Meer was led to an incorrect conclusion in the case of tomato plants. Certain of her own observations contradict her conclusions as she makes the following statements:—"The vessels containing the parasite remain *uncoloured* and the leaves or leaf parts obtaining water from these tracheae remained green," and "the experiments taught that the bacteria in the vessels form column-like masses which lengthen at both sides and branch when lateral ways (leaf petiole or lateral roots) make such possible."

A study of Smith's observations and illustrations (Smith, 1913, 1920), show that in the tomato and potato plants he studied, the invading organism was present in "blocking" numbers at the wilting phase. He, however, expressed no definite opinion as to the cause of wilting. Hutchinson (1913) sponsored the toxin theory of wilting in the case of tobacco plants and described an experiment which he considered proved that mechanical bacterial

blocking could not be responsible. He made a cut half way through the stem of a tobacco plant and inserted a thin strip of plasticene, believing that this would approximate to mechanical blocking in the vessels. No wilting occurred in the leaves above the cut and as he considered that the interference with water supply was greater here than in the case of a bacterially invaded stem, concluded that some other factor must cause wilting of the leaves. Hutchinson's experiment was repeated and others devised to check his interpretation. It was first shown that his expectation of wilting in leaves above a cut blocked with plasticene was not in accordance with water movement in the plant. On placing a plant with its stem locally blocked in the manner he described and with its cut root in eosin solution, the dye passed up the uninterrupted bundles to the apex and then down the far side to the region blocked by the plasticene, passing into all the leaves on the way. This indicated that the localized blocking had caused no real interference with the movement of water and made it clear why no wilting occurred.

Critical experiments were next carried out to test under what conditions of artificial blocking, wilting of leaves in tomato and potato plants would occur. The position of the vascular bundles in the stems of these plants is easily seen when they are placed in front of a bright light, and the procedure was adopted of cutting out very small pieces of the vascular bundles in the stem, just below or above a leaf, in order to interrupt the continuity of the water stream there. Vaseline was used to block the cut regions. Experimental results obtained were as follows:—When one lateral bundle leading to a leaf was cut through and blocked, the leaf remained fresh; when a lateral and a central bundle were cut the leaf still remained fresh, but when in addition the terminal leaflet of the leaf being experimented with was removed, distinct unilateral flaccidity resulted. The removal of the terminal leaflet when one lateral and the central bundle to the leaf are interrupted, prevents the return flow of water from the other uninjured lateral bundle. Again, when in addition to the above treatments the vascular bundle leading to the next leaf above was cut, flaccidity became much more pronounced. On cutting all bundles leading up to a leaf together with the bundle leading to leaves higher on the stem, severe wilting of this leaf occurred in one hour. In certain experiments where only slight flaccidity of leaflets of a leaf occurred after cutting selected bundles, transport of dye showed that not all the vessels of the bundles had been cut and these few intact ones were transporting water. From this it was evident that even a few intact vessels could supply the necessary water to maintain a degree of turgidity in the leaf. The results of these experiments may be correlated with observations on actual occurrences in infected plants; thus the cutting of one lateral leaf bundle fails to induce wilting and is paralleled by the

fact that invasion of one lateral bundle fails to cause wilting, until bacteria in "blocking" numbers grow so far out in the lamina that water cannot be conducted back from the opposite side. Bacterial blocking of two laterals approximated to the cutting of two laterals and of the vascular bundle leading to the second leaf above. The fact that a few intact vessels in a bundle could allow conduction of sufficient water to maintain turgidity in leaves, explains in large measure why leaves of infected plants can remain turgid so long when bacterial invasion is fairly heavy. Not all vessels are blocked, except in the later stages of the disease and the few free vessels can pass sufficient water to keep the leaves reasonably fresh. This turgidity of leaves is not to be confused, however, with the effect of the numbers of bacteria on the rate of transpiration. The volume of water required to keep a leaf of tomato or potato plant turgid under average glasshouse conditions is relatively small (cf. Knight, 1922), while as experiments on companion leaves proved, transpiration may be greatly reduced while leaves still appear quite fresh.

In dealing with the general subject of wilting in plants, Knight (1922) suggested that in the summer, due to a variety of factors, such as increase of atmospheric evaporating power and decrease in soil moisture, a greater tension was placed upon the water columns in the vessels leading to the gradual replacement of water by air, the water columns being severed one by one with the increasing tension until the number remaining unbroken could not supply the leaves with sufficient water to keep the plant alive. The correctness of this conclusion was challenged by Bode (1923) who contended that even in the very last stages of wilting there were no air bubbles in the xylem.

For a clearer understanding of the mechanism of wilting in infected plants these two viewpoints were tested.

Bode's technique was used to determine whether air bubbles developed in vascular bundles of tomato and potato plants showing (*a*) artificially induced wilting due to drying out of the soil, and (*b*) bacterially induced wilting. No bubbles were found in the vessels of tomato plants showing severe wilting due to drying out of the soil so that confirmation of Bode's work was obtained. The examination of bundles of infected plants to see the action of the bacteria proved somewhat more difficult as it was necessary to find the apices of the bacterial masses and to determine whether the water columns were intact above them. The picture finally found was as follows:—Organisms at the head of the growing masses in the vessels were rapidly dividing and were actively motile. The head of the bacterial column advanced due to packing of the organisms. No air bubbles were observed above the bacterial masses in individual vessels. Eosin dye failed to pass upwards through the bacterial mass, but after a longer period dye was observed coming downwards in the vessels above the

bacterial mass having first passed up the free vessels in other bundles. This observation indicated the continuity of the water columns above the bacteria. As stated above no eosin passed from below through the bacterial mass, but the possibility remains that a very small but sufficient amount of water was passing between the packed bacteria to keep the water column intact, but this volume of water was quite insufficient to keep the leaves turgid. These experiments offer no confirmation of the view that actual rupturing of the water columns occurs, rather the reverse because if it were so the bacteria could not grow upward and downwards in the vessels.

Bacterial action in the vessels may be pictured as follows:— The growing bacteria first fill one vessel and interrupt gradually the water flow in it until finally complete blocking occurs, then they spread to a second and repeat the process, and so on, finally few or no vessels in a bundle or bundles leading to one or more leaves are left uninvaded and blocked. Wilting then occurs. The process in the earlier stages is localized and the interruption of the water supply relatively slow. Wilting gradually becomes systemic as the bacteria debouch into and block new vessel groups at the points of junction of bundles in the stem.

Summary.

1. The effect of *Bacterium solanacearum* on the water relations of tomato and potato plants has been analysed in relation to speed of invasion and the production of leaf epinasty and wilting.

2. It has been shown that the march of transpiration in infected and control plants runs parallel until several leaves of the infected plants are showing epinasty and unilateral or bilateral wilting. As increasing numbers of leaves are affected a gradual depression of transpiration rate occurs. The maintenance of a high rate of transpiration in infected plants despite a considerable reduction in effective leaf area in the earlier stages of wilting, was paralleled in experiments on healthy plants in which successive leaves were vaselined. The significance of these results is discussed.

3. The march of absorption in relation to invasion follows a closely similar path to that of transpiration under the same conditions. Where the parasite was inoculated at the stem apex, no reduction in absorption occurred before the bacteria were present in "blocking" numbers in several root vessels after growing downward through the vessels of the stem.

4. The transpiration and absorption experiments, together with eosin transport tests and histological studies, showed in the case of infected tomato and potato plants, that the wilting of leaves was due to gradual mechanical blocking of the vessels by the parasite and not to the presence of tyloses, gum or toxins.

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Explanation of Plate.

Plate XI.

Fig. 1. Leaf epinasty preceding bacterial wilting. No obvious depression of transpiration is occurring at this phase. Expt. 4.

Fig. 2. Wilting due to bacterial invasion. This is the same plant as in Fig. 1, photographed at the close of Expt. 4.

Fig. 3. Photograph of a transverse section at the base of a petiole of a wilted leaf. Note the complete blocking of vessels by bacteria. Breakdown of xylem is also occurring.

1

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3

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Art X.—The Genus Cycloclypeus in Victoria.

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Introduction.
Systematic Study of the Genus *Cycloclypeus*.
Description of Species.
Acknowledgements.
References.

Introduction.

The foraminiferal genus *Cycloclypeus* in Victoria, occurs within very restricted limits in the Batesfordian horizon of the Middle Miocene. The genus was first recognized in Victoria by F. Chapman, who, in 1910, recorded *Cycloclypeus pustulosus* Chapman (1905) in association with *Lepidocyclina* from the polyzoal limestone beds at Batesford near Geelong. In 1930 Chapman and the present author described *Cycloclypeus communis* Martin from the polyzoal limestones of Batesford and Le Grand's Quarry near Longford as well as from No. 3 Bore, Parish of Darriman, no reference being made to the form previously recorded from Victoria by Chapman as *C. pustulosus*. This latter species was described by Chapman from Wai Malikoliko, Santo, New Hebrides, from beds apparently of Lower Miocene age, whilst *C. communis* was originally described by Martin from Middle Miocene beds in Java.

Cycloclypeus is found not only as a fossil but also living in recent seas, especially in the Indo-Pacific region. Deposits of limestones composed almost entirely of tests of *Cycloclypeus* and of Miocene age, occur in North-West Australia, and in New Guinea, whilst a species is fairly common in the Upper and New Quarries at Batesford. The genus is comparatively rare in European fossiliferous deposits, and its only record of recent occurrence in that region is from the Adriatic Sea.

It is not intended in the paper to discuss in detail the morphology and anatomy of the genus. This has been done in some detail by Tan Sin Hok (1932) in his work "On the Genus *Cycloclypeus* Carpenter." In the present short account of *Cycloclypeus* in Victoria the specific determination is made on a study of the nepionic apparatus with some consideration of the external characters. All figured specimens are in the Commonwealth Palaeontological Collection at Canberra.

Systematic Study of the Genus Cycloclypeus.

The first worker to study the genus was Carpenter in 1856, who erected it on recent specimens collected " from a considerable depth of water off the coast of Borneo." His diagnosis of the genus, except for a few minor alterations, still holds good. Tan (1932, p. 15), gives a description of the genus based on Carpenter's specimens—" The *Cycloclypei* can be defined as follows: Shell flat, with or without umbo, with or without pillars, with or without annuli, with or without radial ribs. Contour circular or stellate. Consisting of one single layer of equatorial chambers, in both generations composed of a planispiral nepionic apparatus, surrounded by a neanic apparatus constituted of chambers in concentric arrangement. Sidewalls perforated, without lateral chambers. Marginal cord, septa and sidewalls with canal-system."

Martin, in 1880, was the first to observe the embryonic apparatus in megalospheric specimens.

In 1900, Chapman, in his work on Funafuti, discovered the microspheric form of *Cycloclypeus*. His comparison of this form with the structure of *Heterostegina* is still recognized. Further researches have been carried out by Silvestri and Hofker, whilst Tan Sin Hok (1932) has made extensive investigations regarding both the microspheric and megalospheric forms throughout the Netherlands Indies. Later still, in 1938, Cosijn made a " statistical study of the phylogeny " of the Cycloclypei from Spain.

Both the microspheric and megalospheric generations are found in Victoria, the former being exceedingly rare. The terminology used in describing these forms is based on the works of Tan and Cosijn and is listed below.

Megalospheric Form.

Three distinct stages of growth are discernible in the development of a *Cycloclypeus* shell.

1. *Protoconch or embryonic stage.*—The protoconch consists of two chambers, a rounded central one known as the proloculum, and a kidney-shaped one (the second protoconchal chamber) which surrounds the proloculum. These two chambers constitute the embryonic apparatus, and in the Victorian Cycloclypei they are comparatively small but uniform in size.

2. *Nepionic stage.*—(i) The nepionic apparatus is the series of spiral whorls which originate from the protoconch. The chambers comprising this apparatus show two stages of growth. (*a*) The operculinoidal substage. This is represented by a simple individual chamber, which envelopes one side of the protoconch. This feature is constant in the Victorian specimens. (*b*) The heterosteginoidal substage. This is represented by the divided chambers which follow immediately on the operculinoidal chamber.

(ii) The primary septa or nepionic septa are long septa which run in a vertical direction in the shell, dividing the nepionic whorls into chambers known as primary or nepionic chambers.

(iii) The secondary septa are short septa dividing the nepionic chambers into oblong or rectangular chambers.

(iv) The marginal cord represents the limit of the heterosteginoidal substage.

3. *Neanic or Cyclic stage.*—The neanic stage follows after the development of the nepionic stage, commencing when the spiral or heterosteginoidal method of growth is replaced by the cyclic method, which continues throughout the growth of the shell. This is the true *Cycloclypeus* character.

Microspheric Form.

The microspheric generation is always much larger than the megalospheric form and frequently much less ornamented.

1. The proloculum consists of a single rounded chamber.

2. The nepionic stage consists of a number of small chambers arranged in a spiral.

(i) The operculinoidal substage consists of numerous undivided chambers, instead of one as in the megalospheric form. The microspheric generation in the sections of the few Victorian specimens available has ten chambers.

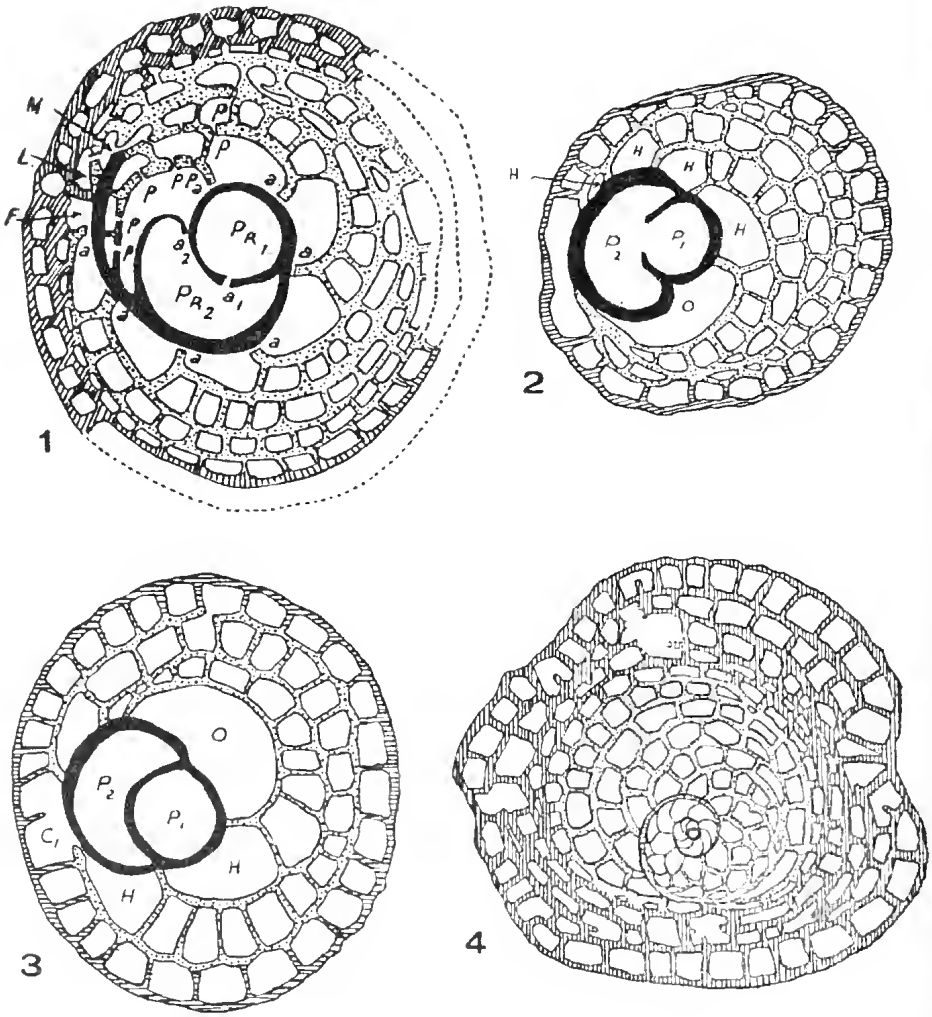
(ii) The heterosteginoidal substage consists of numerous divided chambers which number eighteen in the only satisfactory section of a Victorian specimen.

3. The neanic or cyclic stage is represented where the arrangement of the chambers passes from the spiral to the cyclic.

The structure of more than sixty horizontal sections of megalospheric specimens of *Cycloclypeus* from Victoria has been studied in this investigation, the number of specimens available being nearly four hundred, of these three hundred were from Batesford (one hundred from the New Quarry and two hundred from the Upper Quarry). Only six specimens were available from the Hamilton Bore, and more than one hundred from Gippsland, thirty being from Le Grand's Quarry, twenty from No. 6 Bore, Parish of Colquhoun (Lakes Entrance), and forty from No. 7 Bore. The number of microspheric specimens available was six.

Whilst the external characters show considerable variation, the study of the nepionic septa of numerous specimens leads to the conclusion that only one species is present. This form is being designated *Cycloclypeus victoriensis*. Variation in external sculpture is distinctive in different areas, although at times these variations tend to merge into one another. One variation is so persistent in the Gippsland region that it has been given varietal rank—*C. victoriensis* var. *gippslandica* nov. Tan's remarks on

this group of Cycloclypei (p. 62) might be quoted here: "The great variability of the sculpture of the megalospheric generation is not only shown by specimens of the same population, but also the specimens of separate populations show more or less marked constant differences. It appears that almost each locality yields its own phenotype."



FIGS. 1, 2, 3, 4.—Black, embryonic stage or protoconch; stippled, nepionic stage; hatched, neanic or cyclic stage. Fig. 1. *Cycloclypeus indopacificus* (after Tan) PR_1 and PR_2, 1st and 2nd protoconchal chambers; a_1 and a_2 apertures; seven nepionic septa; P, passages through nepionic septa; *a*, apertures; F, 1st chamberlet of 1st neanic chamber; L, last chamberlet of 1st neanic chamber; M, end of marginal cord. Fig. 2. *C. indopacificus* (after Tan) and fig. 3 *C.* cf. *guembelianus* (after Tan) P_1 and P_2, 1st and 2nd protoconchal chambers; O, operculinoidal substage; H, heterosteginoidal substage; C_1, regular neanic chambers. Fig. 4. Microspheric form (after Tan) nepionic stage with 21 chambers, 10 in operculinoidal substage and 11 in heterosteginoidal substage. Chambers bounded by fine lines, nepionic stage.

The external features of the megalospheric generation of *Cycloclypeus* in Victoria are summarized as follows:—

(*a*) *Cycloclypeus victoriensis*, sp. nov., forma typica—Umbo distinct; pillars strong not only on umbo but on flange, where they are arranged concentrically and with rows fairly close together. Shell fairly thick. Specimens practically uniform in size. Diameter 6 mm. Typical of Batesford and Hamilton with a few specimens at Le Grand's Quarry, Gippsland. Pl. XII., fig. 1.

(*b*) *Cycloclypeus victoriensis* var. *gippslandica*, nov.—Umbo distinct, but not prominent; pillars fairly strong on umbo but finer on flange, where arranged concentrically, but with rows farther apart than in *C. victoriensis*. Test thinner and frequently larger than in the type species. Diameter 2–8 mm. Typical of the Gippsland bores and outcrops in the Glencoe-Stradbroke region, and in bores and outcrops east of Sale, rare at Batesford, absent at Hamilton. Pl. XIII., fig. 10.

Description of Species.

Family CAMERINIDAE.

Genus Cycloclypeus Carpenter.

CYCLOCLYPEUS VICTORIENSIS, sp. nov.

(Pl. XII., figs. 1-3, 5-8; Pl. XIII., figs. 9, 17; Pl. XIV., figs. 20-23; Pl. XV., figs. 26-28, 31-32.)

Cycloclypeus pustulosus Chapman, 1910 (non 1905), p. 295, pl. lii., fig. 6; pl. lv., fig. 4.

Cycloclypeus communis Chapman and Crespin, 1930 (non Martin 1880), p. 112, pl. vii., figs. 7, 8; pl. viii., figs. 9-13.

Cycloclypeus pustulosus Tan, 1932, p. 84.

Cycloclypeus communis Crespin (non Martin), 1936 (pars), p. 7, pl. i., figs. 10, 11.

Holotype.—(A) Megalospheric Generation.—Test circular in outline; umbo distinct, surrounded by a moderately thin flange. Slight annulus or fold immediately around umbo. Test covered with tubercules which are strong and irregularly arranged on umbo but in thirteen concentric rows on flange, which are fairly close together. The tubercules correspond with the annular divisions of the test. Towards marginal portion of test, they develop into radial ridges of varying length extending from the outside margin of each annulus towards periphery of preceding ring of chambers. Diameter 6 mm.; greatest thickness at umbo 1 mm.

The embryonic apparatus is represented by the protoconch which consists of two chambers, a central rounded one, the proloculum, and a kidney-shaped one partially surrounding the proloculum, the second protoconchal chamber. These chambers have a fairly thick shell wall (fig. 20). The embryonic stage is followed by the nepionic stage, the nepionic apparatus consisting

of almost a complete whorl containing ten septa including one operculinoidal and nine heterosteginoidal chambers. This stage is followed by the neanic or cyclic stage in which the majority of chambers are rectangular in shape. The marginal cord, a feature frequently difficult to secure in section, is present in figs. 26, 31, and is represented by a moderately thick wall.

In vertical section, the side walls which lie on either side of the equatorial layer are not thick and are pierced by pillars, which are numerous in the type specimen.

Locality.—White limestone in New Quarry, Batesford, near Geelong at north end of tunnel (collected by F. A. Cudmore). Com. Pal. Coll. No. 157.

Paratypes.—(*a*) Le Grand's Quarry.—The external characters of this specimen are similar to the holotype, except that the edge of the test is smooth and rounded. The nepionic septa are chiefly seven in number. The width of the test is 6 mm., which closely approximates the type.

(*b*) Hamilton Bore at 48–53 feet.—The external features are similar to the holotype, the pillars appearing much stronger in the Hamilton form, due to the preservation of the shell. All the Hamilton specimens are strongly ironstained. A second specimen shows the pillars not quite so prominent, the test being rather smooth towards the margin. The width of both specimens is 5 mm. Horizontal sections were difficult to obtain owing to the mode of preservation.

Observations.—The Batesford specimens of *Cycloclypeus* were recorded by Chapman in 1910 as *C. pustulosus* Chapman (1905), and later by Chapman and Crespin (1930) as *C. communis* Martin, the previous reference as *C. pustulosus* being disregarded. In this latter paper, specimens were also figured from Le Grand's Quarry, Gippsland. No comparison has been made in the present paper with the megalospheric form of *C. pustulosus*, as specimens of that species were not available for this purpose. A horizontal section was not given by Chapman in the original paper, whilst the figure showing the external characters is in no way comparable with the Victorian forms. The Lepidocyclinae associated with *C. pustulosus* in the type locality indicate that this species belongs to a horizon older than that in which *C. victoriensis* is recorded. No specimens similar to that figured from the Batesford limestone could be found amongst the numerous examples examined during this investigation.

Tan (1932, p. 84) in his remarks on *C. pustulosus* as figured by Chapman from the Batesford limestone, states that no specimen corresponding to Pl. 52, fig. 6 could be found in the Javan material. Unfortunately Tan had not seen the figure of the species from the type locality in the New Hebrides, but he does consider that Pl. 55, fig. 4 in the Batesford paper shows relationship with *C. indopacificus*.

As regards *C. communis* Martin, the average diameter of the megalospheric specimens of that form as given by Martin is 12 mm., with the microspheric (not recognized by Martin) up to 40 mm. These dimensions greatly exceed the two generations of the Victorian species. The arrangement of the nepionic septa in *C. victoriensis* is different from that shown by Martin in *C. communis*. In Chapman and Crespin's paper (1930), fig. 13 represents a section of a megalospheric specimen, not microspheric as stated. Douvillé's figures of *C. communis* (1909) from Madagascar show the test to be very closely ornamented with pustules. Tan takes this form (fig. 12) as his type for *C. indopacificus*.

The Victorian Cycloclypei are closely related to *C. indopacificus* of Tan. This authority has suggested that the Victorian form may be slightly more primitive than the Netherlands Indies form, this suggestion being based on the larger number of nepionic septa in the Victorian specimens. Tan considers that the greater the number of nepionic septa the more primitive or older the species, the fewer the septa the younger the form. Six nepionic septa are most frequent in *C. indopacificus*, with variation from four to six, whilst in its variations they range from four to seven, rarely eight. In *C. victoriensis*, the most frequent number is from seven to nine, with three specimens showing ten and one showing thirteen (Pl. XV., fig. 28). In the specimens from the Upper Quarry, Batesford, nine septa are most frequent, whilst in the Batesford New Quarry they number seven, and from Le Grand's Quarry seven.

In studying the populations in a particular locality and bed, certain variations are noticeable. In the Upper Quarry at Batesford where the specimens are numerous, the tests of *C. victoriensis* are uniform in size, being circ. 5 mm. in diameter. Here the type specimen is associated with a comparatively smooth form with a diameter of 3 to 5 mm., whilst the microspheric generation is also represented. The number of nepionic septa varies from seven to ten, with nine the most frequent. In the section in the New Quarry, the diameter of the tests of *C. victoriensis* forma typica, varies from 4 to 8 mm., with the average 6 mm. The number of nepionic septa varies from seven to ten with nine the most frequent. In this section the smooth form and the microspheric generation are absent, but a variety, *C. victoriensis* var. *gippslandica*, is sparingly present.

Very few specimens are available from the Hamilton Bore, these being recorded between the depths of 30 to 38 feet and 48 to 80 feet. All the tests measure 5 mm. and are strongly iron-stained, the internal structure being usually masked by glauconite replacement.

In Gippsland *C. victoriensis* is recorded from Le Grand's Quarry near Longford, where it is fairly common, the average

diameter being 5 mm. The nepionic septa number seven. It is associated with *C. victoriensis* var. *gippslandica, C. victoriensis* forma typica occurs only in two borings throughout Gippsland.

Occurrence.—*C. victoriensis* has been recorded from the following outcrops and borings in Victoria, where it is always associated with *Lepidocyclina*.

Outcrops: (i) Port Phillip Region.—Upper Quarry (Australian Portland Cement Co.), Batesford, near Geelong (Forms A and B), (coll. F. A. Singleton); New Quarry, Batesford, at N. end of tunnel (coll. F. A. Cudmore); Flinders (Forms A and B) (coll. I.C.).

(ii) Gippsland Region.—Le Grand's Quarry, south of Longford, Allot. 13, Parish of Glencoe (Forms A and B) (coll. I.C. and Victorian Mines Department).

Borings: (i) Western Victoria.—No. 1 Government Bore, Hamilton, Parish of Yulecart (4 chains south from bridge over Muddy Creek) at 36-38 feet and 48 to 80 feet.

(ii) Gippsland Region.—No. 14 Bore, Parish of Stradbroke at 705 feet, and No. 1 Bore, Parish of Nindoo at 190 feet.

(B) Microspheric Generation (figs. 6, 23).—(*a*) Batesford specimen—Test large, rather thick, about twice the size of the megalospheric form, measuring about 10 mm. (Complete specimens not available). Umbo district. Test faintly ornamented with pillars, irregularly arranged on umbo, concentrically on flange.

The embryonic stage consists of a protoconch, represented by small, rounded, single chambers. This is followed by a spiral (nepionic) apparatus consisting of twenty-eight chambers (nepionic septa). The operculinoidal substage which immediately follows the embryonic stage contains ten undivided chambers, which are followed by eighteen divided chambers constituting the heterosteginoidal substage. The neanic stage with its cyclic arrangement of chambers immediately follows until the margin of the shell is reached. The chambers in the neanic stage almost quadrate in shape when immediately surrounding nepionic stage, then gradually becoming more and more elongated towards margin of shell.

(*b*) Flinders specimen—Test large, moderately thick, ornamented with fine pillars arranged concentrically on flange. Umbo distinct, represented by swelling towards centre of shell. Diameter—circ. 10 mm.

Observations.—It is unfortunate that specimens of the microspheric form are so rare. As a result of this scarcity the description of the internal characters has been based on one specimen but Tan has shown that the characters of the embryonic and nepionic chambers in the microspheric form are fairly constant. Only three specimens were available from Batesford, all from the Upper Quarry section. One example was available from Flinders, while no specimen was found in the Hamilton Bore.

Occurrence.—Upper Quarry, Batesford, near Geelong (figured specimen of exterior pres. W. J. Parr; sectioned specimen, coll. F. A. Singleton); and Flinders.

Age.—Middle Miocene (Batesfordian).—The stratigraphical horizon is fairly high in the Middle Miocene, and the equivalent of *f 2* stage in the Netherlands Indies, New Guinea, Papua and North-West Australia. This stage probably correlates with the upper portion of the Burdigalian of Europe. The *C. indopacificus* type of nepionic septa is characteristic of this horizon.

CYCLOCLYPEUS VICTORIENSIS var. GIPPSLANDICA, nov.

(Pl. XII., fig. 4; Pl. XIII., figs. 10-16, 18; Pl. XIV., figs. 19, 24, 25, 29, 30.)

Cycloclypeus communis Crespin non Martin, 1936 (pars), p. 7.

Holotype of variety.—(A) Megalospheric Generation.—Specimen incomplete. Umbo distinct, pillars fairly strong on umbo but finer on flange, where arranged in seventeen concentric rows which are farther apart than in *C. victoriensis*. Test larger than in type. Diameter 8 mm.

Embryonic apparatus as in type. Nepionic septa—six. Chambers in the neanic stage tend to become elongated towards margin.

Locality.—No. 5 Bore, Parish of Glencoe at 50 feet. (Com. Pal. Coll. No. 163.)

Paratypes.—(*a*) Parish of Darriman, No. 3 Bore at 439 feet. Test similar to type. Diameter 7 mm.

(*b*) Parish of Nindoo, No. 1 Bore at 190 feet. Umbo less prominent than in (*a*). Test thin and rather wavy. Diameter 6 mm.

(*c*) Skinner's section, Parish of Wuk Wuk, Mitchell River. Umbo not prominent, pillars developing into ridges towards margin of shell. Specimens translucent. Diameter 6 mm.

(*d*) Parish of Colquhoun, No. 7 Bore, 620 feet. Test fairly smooth with pillars scattered irregularly over surface. Umbo indistinct, represented by gradual thickening of side walls towards centre of shell. Nepionic septa, eight. Diameter 4 mm.

Observations.—*C. victoriensis* var. *gippslandica* is found in association with the "forma typica" in Gippsland in Le Grand's Quarry, and in No. 1 Bore, Parish of Nindoo at 190 feet. In no locality was a complete specimen available so dimensions are only approximate.

The main distinction between the two forms lies in the larger size and different and finer ornamentations of the variety. The nepionic septa range from six to eight with six the most frequent. There is also some variation in size and ornament in different populations. At Le Grand's Quarry, except for the presence of

the type species, the majority of the specimens are typical of the type of the variety. In No. 1 Bore, Parish of Nindoo at 190 feet, specimens are comparatively common and some variety in ornamentation and stages of growth is illustrated. The limbation of the outer chambers is very strong, being both radial and concentric. The shell surface is rectangularly reticulated. The dimensions range from 1 mm. up to 8 mm. The shell has not grown beyond the heterosteginoidal stage in the smallest specimens, the surface of the test being smooth and transparent in some and strongly beaded in others. In some of the larger specimens the pillars are so developed as to form strong ridges between the septa. The examples from Skinner's section along the Mitchell River, about 10 miles to the north-east of the Nindoo Bore, show similar characteristics.

C. victoriensis var. *gippslandica* is well represented in the Lakes Entrance (Parish of Colquhoun) bores, specimens varying from 2 to 6 mm. in diameter. The nepionic septa number from six in No. 4 Bore (Pilot Station) to eight in No. 7 Bore (Lake Bunga). Tests are usually rather worn and broken, but in No. 8 Bore (North Arm) they are well preserved and very common. Unfortunately these specimens were not available for inclusion at the time when the plates were assembled.

Occurrence.—Outcrops: (i) Port Phillip Region.—Batesford at top of the New Quarry at the north end of the tunnel (rare).

(ii) Gippsland Region.—Le Grand's and Brock's Quarries south of Longford, Parish of Glencoe (Forms A and B); along the Mitchell River, at Skinner's section, Parish of Wuk Wuk; and north cliff, east of Hillside Bridge, Parish of Wy Yung.

Borings: Gippsland Region.—Parish of Glencoe, No. 5, 50 feet; Parish of Glencoe South, Tanjil-Pt. Addis No. 2 Bore, 560-650 feet; Texland Bore, 330 feet; Parish of Stradbroke, No. 14 Bore, 745 feet; in No. 16 Bore, 610 feet; Parish of Darriman, No. 3 Bore, 379 and 439 feet; Parish of Dulungalong, Signal Hill Bore, 1,573 feet; Parish of Nindoo, No. 1 Bore, 190 feet; Parish of Coongulmerang Steam Drill, 914-916 feet; Parish of Colquhoun, No. 3 Bore (Nungurner), 891 and 893 feet; in No. 4 Bore (Pilot Station), 855 and 860 feet; No. 6 Bore at 887 feet, No. 7 Bore at 620 feet and No. 8 Bore between 565 feet and 590 feet.

(B) Microspheric Generation.—(*a*) Le Grand's Quarry, south of Longford.—Test large, thin, almost smooth but faint pillars are present arranged concentrically on flange. Umbo indistinct. Diameter 12 mm.

The heterosteginoidal chambers are visible but most of the central portion has been altered. In the neanic or cyclic stage, the chambers are elongated rectangular and are fairly close together, this attenuation becoming very pronounced towards margin of shell.

(*b*) Brock's Quarry, south of Longford.—Test large, thin, with uneven surface which is ornamented with faint pillars arranged fairly closely together and concentrically on flange. Twenty-six annuli, visible and irregularly arranged, becoming farther apart as margin of shell is reached, indicating the narrow, elongated chambers shown in horizontal section. Diameter 16 mm.

Observations.—The arrangement of the pillars on the surface of the test and the elongated rectangular shape of the chambers, as shown in horizontal section, leaves little doubt that these specimens from Gippsland represent the microspheric generation of *C. victoriensis* var *gippslandica*. They are also larger than the microspheric forms of *C. victoriensis* from Batesford and Flinders. At the same time, the microspheric specimens of both *C. victoriensis* and *C. victoriensis* var. *gippslandica* are proportionally larger than the megalospheric ones. As with *C. victoriensis*, specimens available for examination were few. Two were present in the material from Le Grand's Quarry and one each from Brock's Quarry and No. 1 Bore, Parish of Nindoo.

Occurrence.—Gippsland Region.—Le Grand's Quarry and Brock's Quarry, south of Longford in the Parish of Glencoe; No. 1 Bore, Parish of Nindoo at 190 feet.

Age.—Middle Miocene (Batesfordian).

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Explanation of Plates.

Cycloclypeus victoriensis, sp. nov.

Plate XII.

Fig. 1.—*Cycloclypeus victoriensis*, sp. nov. N. end of tunnel, New Quarry, Batesford. Exterior of test of Megalospheric specimen. Holotype. No. 157. × 8.

Fig. 2.—Upper Quarry, Batesford. Megalospheric. Paratype. No. 158. × 9.

Fig. 3.—N. end of tunnel, New Quarry, Batesford. Megalospheric. Paratype. No. 159. × circ. 9.

Fig. 4.—Var. *gippslandica* nov. New Quarry, Batesford. Megalospheric. Paratype. No. 160. × 9.

Fig 5.—*C. victoriensis*, sp. nov. Upper Quarry, Batesford. Megalospheric. Smooth specimen. Paratype. No. 161. × 8.

Fig. 6.—Upper Quarry, Batesford. Exterior of portion of microspheric specimen. No. 184. × circ. 6.

Fig. 7.—No. 1 Government Bore, Hamilton, Parish of Yulecart, at 48–53 feet, specimen ironstained. Megalospheric. Paratype. No. 162. × circ. 8.5.

Fig. 8.—Locality similar to Fig. 7. Specimen ironstained. Paratype. No. 83. × circ. 10.

Plate XIII.

Fig. 9.—*C. victoriensis*, sp. nov. Le Grand's Quarry, near Longford. Parish of Glencoe, Gippsland. Megalospheric. Paratype. No. 7. × circ. 8.

Fig. 10.—Var. *gippslandica* nov. No. 5 Bore, Parish of Glencoe, 50 feet. Megalospheric. Holotype of var. No. 163. × circ. 7.

Fig. 11.—Var. *gippslandica* nov. Le Grand's Quarry, near Longford, Parish of Glencoe. Megalospheric. Paratype. No. 164. × 9.

Fig. 12.—Var. *gippslandica* nov. No. 5 Bore, Parish of Glencoe, 50 feet. Megalospheric. Paratype. No. 165. × circ. 8.

Fig. 13.—Var. *gippslandica* nov. No. 1 Bore, Parish of Nindoo, Gippsland, at 190 feet. Megalospheric. Paratype. No. 166. × 9.

Fig. 14.—Var. *gippslandica* nov. No. 7 Bore, Parish of Colquhoun (Lake Bunga), Gippsland Lakes, at 620 feet. Small specimen typical of area. Paratype. No. 167. × 8.

Fig. 15.—Var. *gippslandica* nov. Skinner's section, Mitchell River, Parish of Wuk Wuk (near Bairnsdale). Megalospheric specimen showing regeneration of test. Paratype. No. 168. × 10.

Fig. 16.—Var. *gippslandica* nov. No. 3 Bore, Parish of Darriman, Gippsland, at 439 feet. Paratype. No. 169. × circ. 9.

Fig. 17.—*C. victoriensis*, sp. nov. No. 1 Bore, Parish of Nindoo, Gippsland, at 190 feet. Megalospheric, small specimen. Paratype. No. 170. × circ. 8.

Fig. 18.—Var. *gippslandica* nov. Skinner's section, Mitchell River, Parish of Wuk Wuk (near Bairnsdale). Megalospheric. Specimen showing fairly well marked annuli. Paratype. No. 171. × circ. 9.

Plate XIV.

Fig. 19.—Var. *gippslandica* nov. No. 4 Bore, Parish of Colquhoun (Pilot Station). Horizontal section showing seven large nepionic septa. Annuli in neanic stage irregular. Megalospheric. Tectotype. No. 172. × 20.

Fig. 20.—*C. victoriensis*, sp. nov. New Quarry, Batesford. Horizontal section of megalospheric specimen similar to external of Holotype, showing two protoconchal chambers, ten nepionic septa including one operculinoidal and nine heterosteginoidal chambers. Chambers in neanic or cyclic stage show regeneration. Tectotype. No. 172. × 20.

Fig. 21.—New Quarry, Batesford. Section slightly eccentric. Eight nepionic septa visible. Operculinoidal chamber indistinct. Neanic stage fairly regular. Megalospheric. Tectotype. No. 173. × 20.

Fig. 22.—Upper Quarry, Batesford. Ventral section of megalospheric form showing lateral chambers. Tectotype. No. 174. × 20.

Fig. 23.—Upper Quarry, Batesford. Microspheric specimen, showing elongated character of chamber towards margin of test. Tectotype. No. 175. × 12.

Fig. 24.—Var. *gippslandica* nov. No. 5 Bore, Parish of Glencoe, Gippsland, at 50 feet. Megalospheric. Embryonic apparatus abnormal. Five nepionic septa visible. Neanic or cyclic stage regular. Centre of test partially replaced by glauconite. Tectotype. No. 176. × 12.

Plate XV.

Fig. 25.—Var. *gippslandica* nov. No. 6 Bore, Parish of Colquhoun, Gippsland, at 887 feet. Sections showing nine large nepionic septa. Arrangement of chambers regular around nepionic apparatus. Tectotype. No. 177. × 20.

Fig. 26.—*C. victoriensis*, sp. nov. New Quarry, Batesford. Enlargement of embryonic and nepionic apparatus of Fig. 20. Marginal cord distinct. Tectotype. No. 172. × 40.

Fig. 27.—Upper Quarry, Batesford. Section showing eight nepionic septa, including one operculinoidal chamber and seven heterosteginoidal. Tectotype. No. 179. × 60.

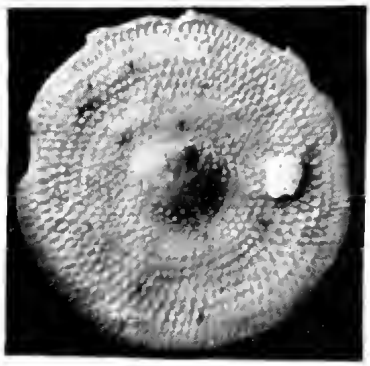
Fig. 28.—Upper Quarry, Batesford. Section showing thirteen nepionic septa (one operculinoidal and twelve heterosteginoidal). Tectotype. No. 180. × 33.

Fig. 29.—Var. *gippslandica* nov. No. 6 Bore, Parish of Woodside, Gippsland. Centre of test filled with glauconite. Two protoconchal chambers of embryonic apparatus unusually large and thick-walled. Marginal cord distinct. Tectotype. No. 181. × 60.

Fig. 30.—Var. *gippslandica* nov. Le Grand's Quarry, near Longford, Parish of Glencoe. Section showing seven nepionic septa. Tectotype. No. 182. × 60.

Fig. 31.—*C. victoriensis*, sp. nov. New Quarry, Batesford. Section slightly oblique. Seven nepionic septa visible. Wall of embryonic apparatus thick. Marginal cord distinct. Tectotype. No. 183. × 60.

Fig. 32.—Upper Quarry, Batesford. Microspheric, specimen showing one protoconchal chamber, ten operculinoidal and eighteen heterosteginoidal chambers. Tectotype. No. 178. × 60.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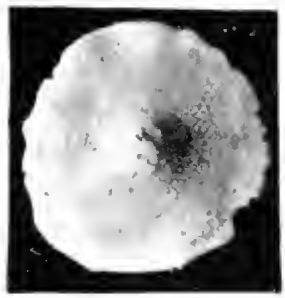
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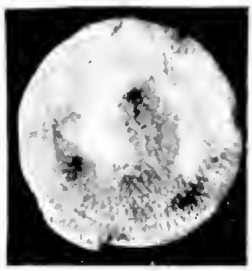
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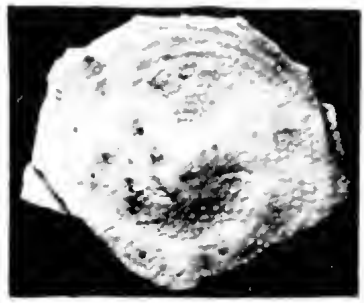
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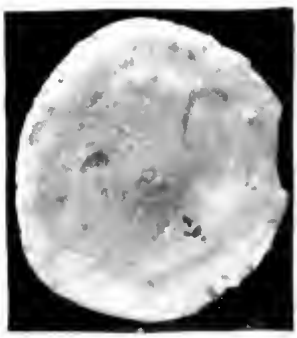
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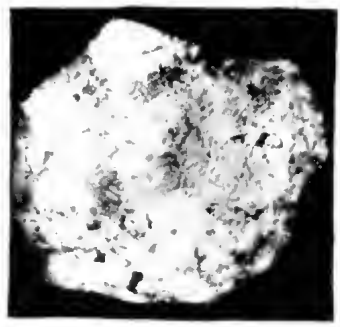
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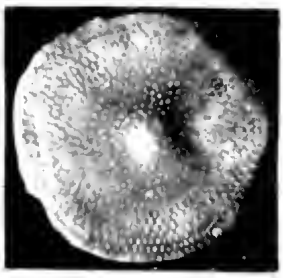
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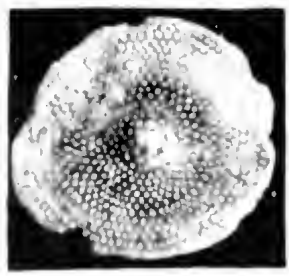
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Cycloclypeus from Victoria.

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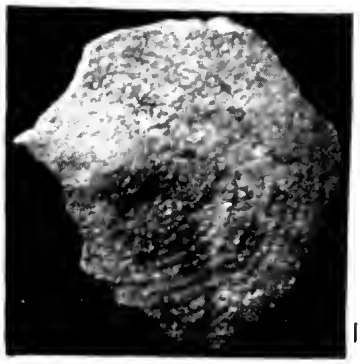
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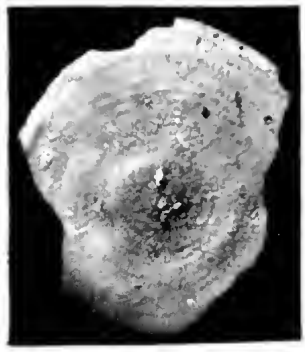
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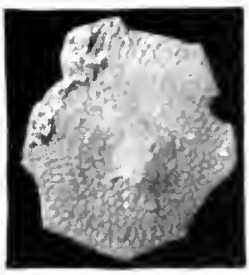
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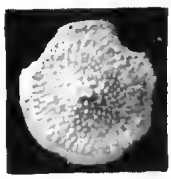
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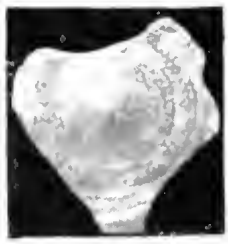
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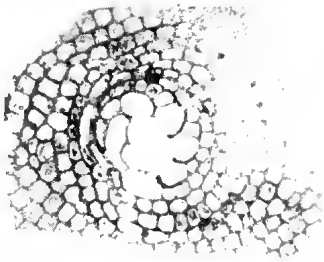

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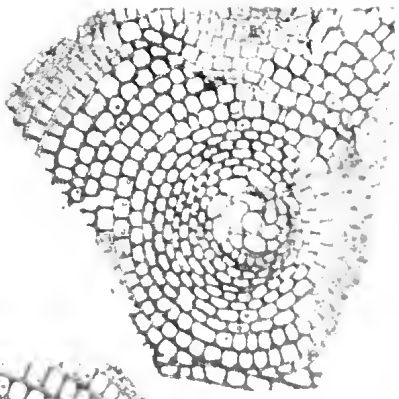

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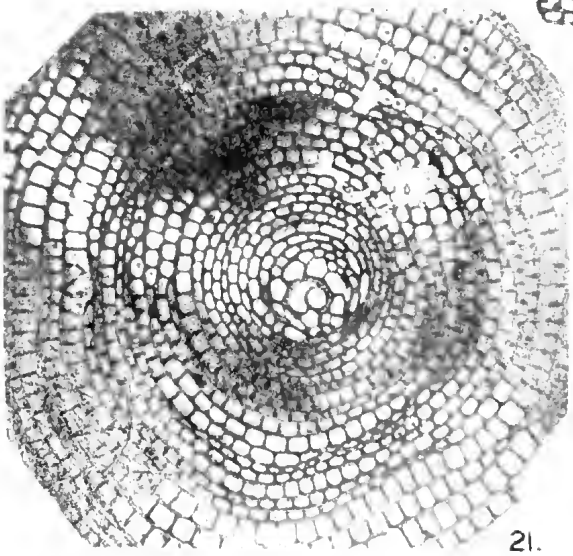

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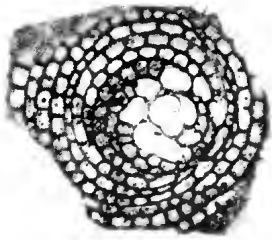
Cycloclypeus from Victoria.



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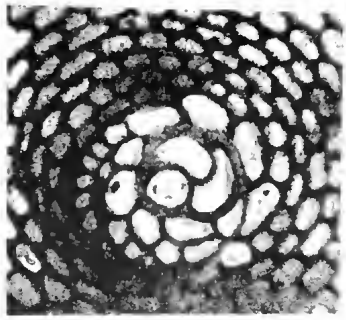

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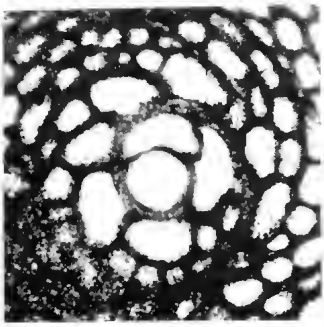

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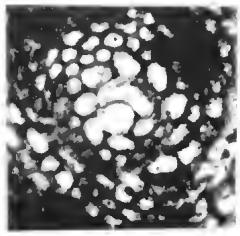

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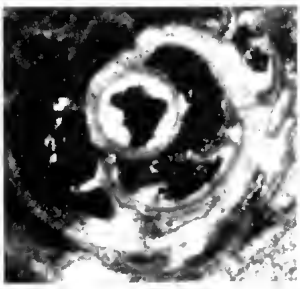

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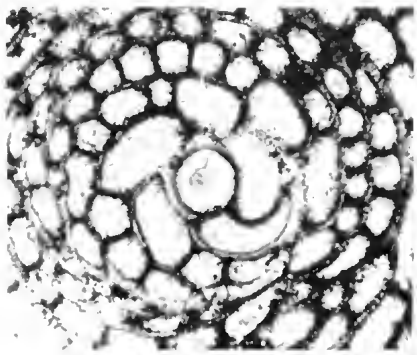

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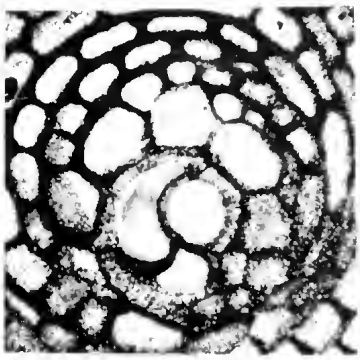

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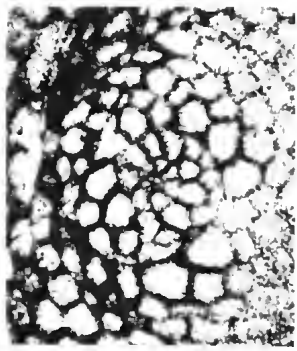

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Cycloclypeus from Victoria.

[Proc. Roy. Soc. Victoria, 53 (N.S.), Pt. II., 1941.]

Art. XI.—*Studies in the Physiology of Host-Parasite Relations.*

II. Adventitious Root Formation.

By B. J. GRIEVE.

Botany School, University of Melbourne.

[Read 14th November, 1940; issued separately 26th July, 1941.]

Introduction.

Recent advances in the study of the response of healthy plants to growth substances have suggested the possibility of their being concerned in similar stimulation effects induced in plants infected by certain bacterial pathogens.

Three pathogenic organisms which induce atypical growth response in some host plants are *Bacterium solanacearum* (Bacterial Wilt of Solanaceae), *Aplanobacter michiganense* (Bacterial Canker of Tomato) and *Bacterium tumefaciens* (Crown Gall).

The production of adventitious roots on intact stems of tomato is induced by all three organisms, epinasty of leaves and stimulated cambial activity are induced by *B. solanacearum* and *B. tumefaciens,* while cell proliferation leading to gall formation is characteristic of *B. tumefaciens.*

In an earlier paper (Grieve, 1939) the epinastic response of leaves, induced by *B. solanacearum,* was examined and the question of its proximal cause discussed. Epinastic response of leaves, adventitious root formation and cambial stimulation induced in plants by *B. tumefaciens* and the relations of these effects to growth substance has been studied by Locke, Riker, and Duggar (1938). The present paper deals firstly with observations on the development of adventitious roots in plants invaded by *Bacterium solanacearum* and secondly with their relation to growth substance, comparisons being made with similar effects induced by humidity, gravity, wounding, blocking, synthetic growth substances and by the two other organisms referred to above.

That tomato plants react to invasion by *B. solanacearum* by the formation of adventitious roots was first indicated by Ilmger in 1901. His observations were confirmed by Smith (1914, 1920) who demonstrated that adventitions roots arose above and below the point of inoculation whereas no adventitious roots developed on control stems pricked with a sterile needle. Smith also

demonstrated that adventitious roots developed on infected tobacco stems. Bryan (1915) while working with tall and dwarf varieties of garden nasturtium (*Tropaeolum majus*) observed that the tall varieties reacted to bacterial invasion by adventitious root formation.

Hutchinson (1913) and Smith (1920) made tentative suggestions as to the proximal cause of this stimulation effect but no critical investigation appears to have been attempted.

The present work was commenced when the characteristic development of the roots was observed in artificially infected tomato plants (Grieve, 1936A).

Methods.

In the case of *Bacterium solanacearum* the technique of inoculation, the cultures used and the methods of fixing and staining infected material were as described in an earlier paper (Grieve, 1939). The culture of *Aplanobacter michiganense* used was a strain isolated from tomato in Victoria by A. Pugsley of the Department of Agriculture, and the Crown Gall organism was a strain isolated from almond (Grieve, 1934).

Test plants were grown in a glasshouse during spring and summer months, minimum night temperatures being approximately 58°F. and average day temperatures ranging from 65°F. to 80°F. The following plants were examined for adventitious root formation after infection by *Bacterium solanacearum*:—*Lycopersicum esculentum* Mill., *Solanum tuberosum* L., *Solanum nigrum* L., *Solanum dulcamara* L., *Tagetes erecta* L., *Helianthus annuus* L., *Tropaeolum majus* L., *Ricinus communis* L., and *Impatiens balsamina* L.

After determining experimentally which plants showed the reaction, further experiments were made with those in which it developed most conspicuously. Tomato plants only were used for observing stimulation effects due to *Bacterium tumefaciens* and *Aplanobacter michiganense*.

For observations on the outgrowth of adventitious roots under humid conditions the plants were placed under bell jars or in large glass cases.

To ascertain the effect of gravity on adventitious root formation in tomato, experiments were performed in which some plants were staked horizontal and others rotated on a klinostat in order to neutralize the effect of gravity. All these plants were kept under humid conditions.

Experiments to determine the concentration of β-indole-acetic acid necessary to cause approximately equivalent adventitious root formation on tomato and other plants were made using water

solutions contained in small glass tubes drawn to a capillary at one end. The capillary end of the tube was inserted into the stem in the vicinity of a vascular bundle and its contents allowed to drain slowly into the plant. Each tube had a capacity of about 0.4 cc. and the concentration was 0.03 per cent. Lanoline-water emulsions of β-indole-acetic acid were used in some of the experiments relating to the effect of gravity and of growth substance on adventitious root formation.

The presence of growth substances in liquid media in which cultures of the organisms named earlier had been grown (for composition of media used see Grieve, 1939) was detected using the ether extraction procedure of Thimann and Bonner (1933) with *Avena* coleoptile tests. The *Avena* tests were made according to Went's technique (1928) and "Victory" oats were used. The husked oats were soaked for two hours, then the water was poured off and they were left in light for a further seven hours. They were then transferred to petri dishes lined with moist filter paper and germination allowed to proceed for about 30 hours. By this time the coleoptiles and roots were well developed and the seedlings were planted in individual holders with their roots in water and grown in a compartment held at 25°C. and 90 per cent. relative humidity. When the coleoptiles had reached a length of approximately 3 cm. they were ready for use and the standard method of decapitation and application of the agar blocks mixed with extracted growth substance was followed. Dolk and Thimann's method (1932) of preparation of agar blocks mixed with extracted growth substance was used, the final volume of each block for application to a decapitated coleoptile being 10.7 cmm.

For comparing growth substance content of stem parts of inoculated and healthy tomato plants the diffusion method was first tried, in which comparable stem parts from test and control plants were placed on agar plates of a size 8 × 10.7 × 1.5 mm. for two hours. Each agar plate was then cut into twelve small blocks of equal size and these applied to decapitated coleoptiles. Satisfactory results for tomato were only obtained, however, when stem portions close to the apex were used. Overbeek's ether extraction method (1938) was next tried and as more satisfactory results were obtained it was used for most of the experiments. In comparing the growth substance content of the plants, equal fresh weights of stem parts were extracted separately.

The experiments on mechanical blocking of bundles were made using cocoa butter, lanoline and a paraffin wax-vaseline mixture. The blocking substances were introduced in the melted state through incisions in the plant stems.

Observations on Adventitious Roots in Healthy Plants.

Adventitious roots may be defined as those which arise in unaccustomed places and for the purposes of this paper are limited to those which develop on the stems of intact plants. In origin they are endogenous, developing by the formation of apical root meristems from the pericyclic regions in the vicinity of the outer phloem groups. Owing to the fact that these adventitious roots sometimes develop on healthy plants, a study was first made of some of the determining factors. Observations extending over fortnightly periods, were made on batches of tomato, sunflower, garden nasturtium, balsam, black nightshade, African marigold and potato plants of varying ages which were growing quite straight in the glasshouse. Only a very sparse development of adventive root primordia was observed in tomato, African marigold and balsam plants and none in the other plants.

The adventitious roots visible at the surface as small nodular projections covered by the epidermis, were confined to the basal internodes in tomato and to 1 to 2 inches above soil level in African marigold. The plants were next grown for fourteen days in highly humid conditions under bell jars and glass cases. Only a slight increase in the number of root primordia was observed. Very rarely did these root anlage pierce the epidermis and grow out into the humid atmosphere. It has frequently been observed in tomato plants which bend over sideways (often as a result of watering) that adventitious root primordia develop in some abundance along the lower side of the stem. This suggested that gravity was an important factor and experiments extending over fourteen days were performed in which stems of tomato plants were staked horizontally, both under normal and under very humid conditions. Root primordia developed on the lower side of the stems over several internodes up to the point where the unstaked tips turned upwards. This observation confirmed that made earlier by Laibach and Fischnich (1935), but the experiment was next carried further by rotating tomato plants with their stems held in a horizontal position on a klinostat for ten to fourteen days. No trace of adventitious root formation, even under very humid conditions occurred over the length of such horizontally rotated stems. These experiments made it clear that gravity and not humidity was the dominant causal factor in adventitious root formation in tomato. The development of these roots on the lower side of the horizontally staked stems where gravity is exerting its effect, was suggested by Laibach and Fischnich (1935) to be due to some movement of root forming substance from the upper to the lower side. In the experiments where the plants were rotated on the klinostat, each side of the stem was successively subjected to the influence of gravity and it is suggested that under these conditions no such localized accumulation of root forming substance can occur and no adventitious roots develop. Support for this view was given by

further experiments in which β-indole-acetic acid in lanoline was smeared for 1 inch along the upper surfaces of plant stems staked horizontally and for a comparable distance along one side of stems of plants ready for rotation on the klinostat. In the former case, root primordia developed over the upper treated region as well as along the lower surface, while in the rotated stems root primordia developed only along the line of growth substance smear. It was observed, even in the plants staked horizontally under humid conditions and where numerous root primordia became visible at the surface, that these only occasionally broke through the epidermis and grew out into the moist air. When such stems were staked horizontally in contact with moist soil or moss, however, the adventitious roots grew out speedily. These results suggest that contact stimulus is important in relation to the outgrowth of the roots which develop in response to gravity effect. It should be noted that this contact stimulus is not necessary for the outgrowth into humid air of adventitious roots when these are induced by growth substances or by bacterial infection.

Having defined the conditions and degrees of development of naturally forming adventitious roots in test plants, attention was next directed to ascertaining those host plants in which bacterial infection by *Bacterium solanacearum* stimulated definite root formation.

Range of Host Plants which Develop Adventitious Roots.

The pathogen *B. solanacearum* was inoculated either at the apex or base of the stems of test plants. Control plants were pricked in the same regions with a sterile needle to serve as a check on normal adventitious root formation. Conditions in the glasshouse were such that the air in the vicinity of the plants was humid but no attempt was made to place the plants under very humid conditions. Results are expressed in Table I.

TABLE I.—TEST FOR ADVENTITIOUS ROOT FORMATION IN PLANTS INFECTED BY *B. solanacearum*.

TEST PLANT.	RESULT
Lycopersicum esculentum	
var. Marglobe	+
,, Burwood Wonder	+
,, Dwart Champion	+
Trapaeolum majus	
Tall variety	+
Dwarf variety	+
Tagetes erecta	+
Helianthus annuus	+
Solanum nigrum	+
,, *dulcamara*	+
,, *tuberosum*	+
Ricinus communis	+
Impatiens balsamina	+

+ + + signifies a large number of induced roots. − signifies no roots.

The tomato variety Marglobe consistently showed the greatest number of adventitious roots developing, both above and below the inoculation point, and was consequently used as the main test variety for the experiments to be described later. The observations of Bryan (1915) regarding adventitious root formation on infected tall varieties of *Tropaeolum majus* were confirmed and it was also demonstrated that under the conditions of slow invasion in some of these experiments adventitious root formation could occur in dwarf varieties. The records of root formation on *Tagetes erecta* and *Helianthus annuus* are new. The effect was so definite in the former case that this plant was selected for additional experiments. Considerable difficulty was experienced in obtaining successful inoculations on sunflower plants, but in those cases where the disease occurred root primordia were found developing along the invaded bundles. Control plants pricked with a sterile needle showed a complete absence of such root primordia. No confirmation was obtained for the report by Stanford and Wolf (1917) that *Impatiens balsamina* reacted to invasion by adventitious root formation. The inoculation points were 1½ to 2 inches above soil level and no roots developed above this level. The occasional development of roots, at or about soil level, was found to occur both in infected and healthy plants when held under humid conditions. Infected balsam plants showed marked browning of vessels (visible externally) due to gum formation, this being followed by wilting of leaves. Plants of *Solanum nigrum* and *Solanum dulcamara* wilted without development of roots, even when placed under conditions favouring slow invasion. Infected potato plants showed the stimulation response of leaf epinasty but no trace of adventitious root formation on the stem was observed.

Considerable variation, even between plants of closely similar size and vigour, was found in the period for the development of bacterially induced roots to the stage where they were clearly recognizable at the surface. This variation is probably due to the more rapid growth of the pathogen in one plant than another owing to more favourable implanting.

For tomato the minimum time for the adventitious roots to show as nodular swellings under the epidermis was found to be four days. This was recorded from three Marglobe tomato plants growing under conditions suitable for fairly rapid invasion. The majority of records, however, showed that six to ten days elapsed after inoculation before the roots were clearly distinguishable. Longer periods, extending from 14 up to 28 days, were recorded under conditions of slow invasion during autumn months. Under environmental conditions which favoured rapid invasion wilting occurred in tomato plants (6 to 8 inches tall) without any sign of root formation. Sections of stems of such plants failed to show any indication of the start of root primordia. Younger

tomato plants (3 to 4 inches tall) wilted without developing adventive roots even when invasion was retarded. Under optimum conditions invasion progressed more slowly in African marigold than in tomato, the minimum time recorded for root development to the nodule stage was fifteen days. The average time was 26 to 30 days. The invading bacteria were seldom present in the stem vessels in "blocking" numbers as in tomato and their rate of movement in the stem was much slower. The adventitious roots which developed were quite comparable in numbers to those on tomato plants.

Regions of Development of Adventitious Roots.

In naturally infected tomato plants adventitious roots developed characteristically along the path of the primary bundles, spreading later to the secondary tissues. Under conditions of moderately rapid invasion in plants 8 to 10 inches tall (wilting commencing in 12 to 15 days), adventitious roots were observed over as many as seven or eight internodal regions. They did not commonly develop in apical regions. Artificial inoculations by needle prick were generally made in the vicinity of the primary bundles. Definite root formation occurred both above and below the prick as the bacteria multiplied and the bacterial columns spread upwards and downwards in the vessels. Hunger (1901) observed that adventitious roots developed on tomato leaf petioles as well as on the stem. In the course of this investigation, however, none has been seen to develop on leaf petioles.

The root primordia which developed were very variable in number on different tomato plants. The average number was between 40 and 50, extending over four to five internodes, with maximum numbers of roots ranging up to 200. On the other hand as few as five to six primordia definitely associated with the disease were recorded. In control plants as many as five to six naturally occurring roots were recorded in basal internodal regions.

For African marigold and garden nasturtium the development of the induced roots was along the course of the bundles and the numbers developing were comparable in any internode to those on tomato. In sunflower the numbers of induced roots were few.

The Effect of Humidity on the Outgrowth of Bacterially Induced Roots.

Under normal glasshouse conditions the individual roots develop no further than nodular projections covered by the epidermis, but when test plants are placed under humid conditions in glass cases or under large bell jars a large proportion, but not all, of the nodules force their way through the epidermis and grow out into the humid atmosphere. The length to which these roots grow out varies from $\frac{1}{4}$ inch to 2 inches. It was noticeable that

the greatest tendency for strong outgrowth of roots was in the lower internodes, but outgrowth from apical internodes was also recorded (Pl. XVI., fig. 1). Examination of Pl. XVI., figs. 1, 2 and 4, show that both in tomato and African marigold a number of the nodules fail to grow out. Sections through these have shown the presence of bacteria in large numbers in the vessels behind the root primordium. After some days the tips of several of the roots which grew out showed browning and no further growth occurred. Quite a long period elapsed however before any further breakdown changes were observed, even though test plants were in many cases badly infected and showing bacterial ooze at the surface of the stem.

In other experiments stems of infected plants were cut near the base and placed in a beaker of water under a bell jar. A much higher proportion of the nodules broke through the epidermis and grew out into the humid air (Pl. XVI., figs. 1 and 4). This increased outgrowth as compared to that on intact plants may be due, at least in part, to the diffusion of the "blocking" bacteria from the vessels allowing the transport of more water to the root primordia. As indicated earlier, intact healthy plants held under humid conditions have only rarely shown outgrowth of adventitious roots and these also were confined to the basal internodes. When cut stems of such plants were placed in water, roots developed in considerable numbers below the water surface. This contrasted strikingly with the appearance of infected plants, where the adventitious roots developed conspicuously on the stem both above and below the surface of the water.

Comparison of Adventitious Root Formation by *B. solanacearum*, *B. tumefaciens* and *A. michiganense*.

Adventitious root formation in tomato plants inoculated with *B. tumefaciens* did not compare in numbers, or in longitudinal distribution on the stem, with those induced in similar plants infected with *B. solanacearum*. Even when inoculations were made at five or six points on the stem as Locke, Riker and Duggar (1938) recommended, the numbers of roots, which were closely associated with the galls, did not approach in numbers those induced by the bacterial wilt organism. This difference in numbers and distribution is of course related to the rather localized nature of invasion in Crown Gall, as against the systematic development in bacterial wilt of Solanaceae. When placed in a humid atmosphere, outgrowth of the root nodules occurs in the same manner as do those in plants infected with *B. solanacearum* but no browning and breakdown of the outgrown roots was seen to occur in Crown Gall. No evidence has so far been presented to show that *B. tumefaciens* is present at the base of such developing roots as is often the case for *B. solanacearum*.

Adventitious root development induced in tomato by *Aplanobacter michiganense* was variable. In some cases the numbers were comparable to those induced by the bacterial organism causing wilt, but more often the numbers visible at the surface were few, and swelling and cankering of the stem occurred. Under humid conditions comparatively few of the root nodules grew out into the moist air and most of those that did so, rapidly browned and withered. Longitudinal and transverse sections through such roots showed the parasite invading and corroding the vascular system of the root. *A. michiganense* is primarily a phloem parasite and consequently is in a favourable position to attack root primordia shortly after they commence development. Even at the nodule stage, considerable corrosion of the vascular tissues of the embryo root has been found to occur, this being responsible for their failure to develop further when placed under humid conditions.

Comparison of Bacterially Induced Roots and those induced by Growth Substance.

During the course of the above experiments comparative tests were made on selected plants using a synthetic growth substance (β-indole-acetic acid) applied in aqueous solution at an experimentally determined concentration (0.03 per cent. in water), which gave comparable stimulation responses to those observed in infected plants. It was noted that adventitious root formation occurred in much greater abundance over a somewhat localized zone on the stem close to the point of uptake of the growth substance. The systemic nature of bacterial invasion causing wilt makes this difference quite understandable. Where growth substance was introduced into the vascular system of plants and travelled with the transpiration stream, the systemic invasion effect was paralleled in so far as leaf epinasty and adventitious root formation were concerned. Frequently stem bending was observed in tomato plants treated with growth substance, but no comparable effect has been seen in invaded plants. Swelling of the stem and increased cambial activity, after application of growth substance, has sometimes been paralleled in infected plants. Hunger (1901) recorded the development of adventitious roots on the petioles of plants infected by *B. solanacearum* and roots appear in this position on tomato plants treated with β-indole-acetic acid. Under normal glasshouse conditions the roots induced by the growth substance do not develop beyond the nodular stage, but under humid conditions they break through the epidermis and grow strongly out into the moist air for a distance of 1 to 2 inches. The time for this development, from the date of uptake of growth substance, varied between six and twelve days. When the plants were placed under humid conditions at the stage when nodules were

showing at the surface, two to three days sufficed for strong outgrowth. These times were similar to those for outgrowth of the roots in plants infected by *B. solanacearum*. When growth substance in aqueous solution was allowed to drain into stems of infected plants, which were already showing some degree of leaf epinasty and adventitious root formation, an additive effect was obtained in that more roots grew out and previously unaffected leaves developed epinasty. When growth substance in lanoline was smeared along the lower surface of a bacterially reflexed petiole the epinasty was overcome, and when the concentration was increased such previously reflexted petioles assumed a hyponastic position.

Histological Observations on Bacterially Induced Roots.

Considerable interest attached to determining whether the induction of adventitious roots by *B. solanacearum* was due to local action or to action at a distance. Hutchinson (1913) and Smith (1914, 1920) were of the opinion that the development of adventitious roots occurred in the local absence of bacteria. Both show photomicrographs of developing roots and point out that no bacteria are present in the vessels behind them. From a detailed histological study of numerous infected plants the author believes that the picture presented by these workers must be modified. In transverse sections all conditions were found ranging from heavy bacterial blocking in vessels immediately behind the developing root to complete absence of bacteria. In the majority of cases, however, for tomato, sunflower, and African marigold stems, the bacteria were present in some vessels in the regions where adventitious roots were developing. Frequently the bacteria-filled vessels as viewed in transverse section were separated radially from the zone of root development by three to four locally non-invaded vessels, while in other instances bacteria were present in vessels on either side of the embryonic root, while the vessels immediately behind it were free. Typical conditions are represented in fig. 1 and Pl. XVI., fig. 5.

Transverse sections, however, gave only a limited picture of the relation of the bacteria to the adventitious roots. A much clearer and more complete picture was given by combining observations on transverse sections with the examination of series of longitudinal sections, and observations on the path of vessel invasion as determined using a staining and maceration method (Grieve, 1936b). Using this latter method it was possible to demonstrate with a minimum of labour that the majority of the adventitious roots developed approximately along the lines of the larger primary bundles which were being invaded. In only rare instances did roots develop close to invaded median trace bundles.

Where infected plants were large and a considerable amount of secondary growth had taken place, adventitious roots were found at points other than the large primary bundles. A study of longitudinal and transverse sections through stem regions bearing adventitious roots at various degrees of development (i.e., from root primordia in the incipient stage to well developed nodules visible at the surface) showed the following relations of the

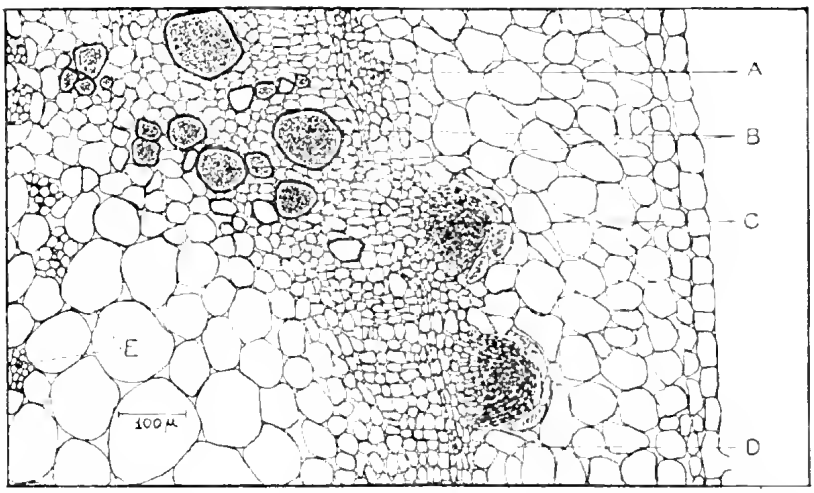

FIG. 1.—Transverse section of tomato stem showing adventitious roots in relation to invaded vessels. A = external phloem, B = vessels full of bacteria, C = Adventitious root, D = cambium, E = internal phloem. Camera lucida drawing.

bacteria to the roots:—(*a*) Adventitious roots frequently commenced to develop ahead of advancing columns of bacteria in vessels. (*b*) Bacteria were often found growing in the vessels closest to the stimulated root, but the presence of bacteria even in vessels which were separated by other tissues from the region of root development, does exert a stimulating effect (fig. 2). (*c*) Development of root primordia once initiated continues to the stage where the root becomes visible as a nodule at the surface of the stem, even though the bacteria during this period gradually block those vessels nearest the incipient root. Bacteria have even been observed passing into the tracheal system of a young root without immediately inhibiting its development (Pl. XVI., fig. 5). (*d*) Where most of the vessels in a main primary bundle were showing bacterial invasion, root primordia were stimulated to develop on either side of the blocked bundle (fig. 1). (*e*) Where the speed and completeness of invasion is very rapid so that

vessels are filled with the pathogen within a few days, leading to severe wilting, no adventitious roots have been observed to develop.

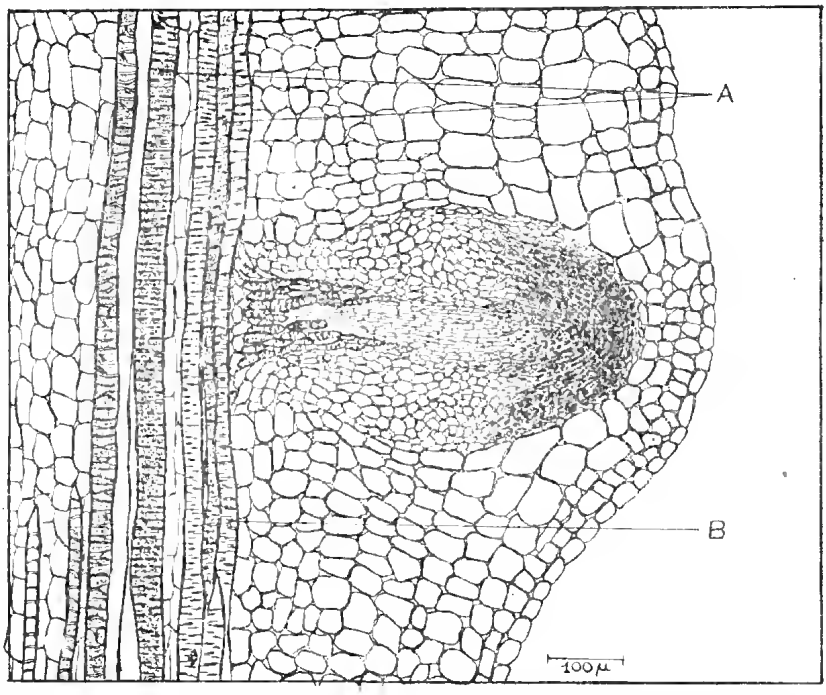

FIG. 2.—Longitudinal section through tomato stem showing relation to the bacteria to the young root. A = vessels in which bacteria are present, B = vessel closest to root primordium. No bacteria are present. Camera lucida drawing.

Growth Substance and Adventitious Root Formation.

The production of adventitious roots, stem swelling and leaf epinasty in plants infected by *B. solanacearum* parallels these effects induced in healthy plants by the application of growth substances such as β-indole-acetic acid. This raises the question as to whether growth substance is associated with the formation of adventitious roots in such infected plants. In an attempt to answer this, the growth substance content of equivalent stem portions of healthy and infected tomato plants, which were of closely similar size and equal vigour prior to inoculation, was compared. The agar diffusion method method of extraction of growth substance was used in preliminary experiments, but was discarded later in favour of the ether extraction method. Sixteen technically successful experiments were carried out but

only in five were there appreciable differences between the content of growth substance of healthy and infected plants. The results are set out in Table II.

TABLE II.—DIFFERENCE IN PLANT UNITS (AS PERCENTAGE OF CONTROL) BETWEEN THE CONTENT OF GROWTH SUBSTANCE OF HEALTHY AND INFECTED PLANTS.

EXPERIMENT NUMBER.	DIFFERENCE.
3, 7, 18, 20, 22	+ 13, + 14, 27, + 44, + 50
10, 12, 17, 19, 21	+ 1·5, + 1·4, 2·1, + 3·5, + 1·4
4, 8, 13, 15, 14	3, 1·9, 3, + 2, 0

+ Indicates that infected plants contain more than the control. The total content of the controls varied from 67 to 198 plant units.

In spite of the large positive differences recorded in the first group of experiments, statistical examination shows that the difference between infected and healthy plants is not significant (either at the 1 or the 5 per cent. level). Further experiments of this kind are in progress, but it should be borne in mind that very small amounts of active substance suffice to cause marked stimulation effects and also that some of it would be used up in initiating the root primordia.

Should it eventually be found that there is a significantly greater amount of growth substance in infected plants showing root formation, it would still be necessary to discover its origin, that is, to find out whether it was produced as a result of bacterial metabolism or by the host cells as a reaction to invasion. The approach to this problem must necessarily be indirect. In the case of Crown Gall some workers have shown that *B. tumefaciens* could produce growth substance in culture media. Brown and Gardner (1936-37) and Link, Wilcox and Link (1937) inclined to the view that part at least of the stimulation effect was due to the production of heteroauxin by the pathogen. It had been shown earlier (Grieve, 1939), that *B. solanacearum* produced a growth substance in culture media containing peptone, glucose and mineral salts. Further studies showed that both virulent and non-virulent cultures of *B. solanacearum* produced approximately equal amounts of growth substance as determined by the *Avena* test. The same result was obtained when pathogenic and non-pathogenic cultures of *Aplanobacter michiganense*, *B. tumefaciens*, and *B. flaccumfaciens* were tested. The active substance, extracted in crude form, gave positive tests for heteroauxin and induced adventitious roots on application to tomato and African marigold plants (Pl. XVI., fig. 3). The fact that all the organisms named above produce growth substance in culture

media irrespective of whether they are pathogenic or non-pathogenic, or of whether they produce stimulation effects in their host plants, makes it doubtful, that such a mechanism is necessarily involved in infected plants. Moreover, as Locke, Riker, and Duggar (1938) observed in the case of Crown Gall, the volume of culture which must be extracted and the number of bacteria present to give a small amount of growth substance, greatly exceeds the volume of sap and the number of bacteria present in the invaded plants, where the stimulatory effect is more marked.

On the question of the possible production of heteroauxin by the bacteria in the invaded vessels, more direct evidence was sought by an experiment which involved the uptake of the amino acid tryptophane into plants. The rationale for this experiment was as follows:—The production of growth substance (hetero-auxin) by bacteria in media containing tryptophane follows the course of oxidative de-amination (Thimann, 1935).

$$\underset{\text{tryptophane}}{C_8H_6N.CH_2.CH(NH_2).COOH} + O_2 \xrightarrow{\text{bacterial action}} \underset{\text{hetero-auxin}}{C_{10}H_9O_2N} + NH_3 + CO_2$$

If such a process of oxidative de-amination was taking place in the invaded vessels where the amino acid tryptophane might be expected to be present, it seemed reasonable to assume that an artificial increase in the concentration of this substance would lead to a greater production of growth substance by the bacteria and the presence of this in turn would be reflected by more pronounced epinasty of leaves and adventitious root formation. To test this the following procedure was adopted. Ten tomato plants of closely similar size and of equal vigour were all inoculated with standard inoculum at the same height in a main bundle. Two days later 0.4 cc. of a 0.5 per cent. concentration of l-tryptophane was allowed to drain from small tubes into the inoculated bundles of five of the test plants. At the same time 0.4 cc. of water was allowed to drain into the inoculated bundles of the other five plants. Plants were examined from day to day for epinasty of leaves and adventitious root formation. No evidence was obtained, however, to indicate that any increased production of growth substance due to the addition of tryptophane occurred, the degree of epinasty and of adventitious root formation being approximately the same in both series. Wilting supervened earlier in the plants supplied with tryptophane and sections showed more bacteria in the vessels of these plants than in those of the control plants. Since 0.4 cc. of a 0.5 per cent. concentration of tryptophane when allowed to drain into a healthy plant has no deleterious effect, it is concluded that the tryptophane in the above experiment was utilized as a food source by the parasite and the increased numbers of bacteria caused the earlier wilting of the plants. This experiment lends no support to the hypothesis

that *B. solanacearum* produces growth substance by acting on naturally occurring tryptophane in the xylem sap. It is possible that under certain conditions tryptophane present in the vessels may be acted upon to give heteroauxin, but the above result, taken in conjunction with the results for growth substance formation in culture media, makes it appear unlikely that the production of heteroauxin by the parasite plays any major role in the induction of adventitious roots in infected plants.

The alternative view is that the stimulation effects might be due to excessive production of growth substance by the plant tissues under the influence of the bacteria (suggested in the case of Crown Gall by Leonian (1937), and Locke, Riker and Duggar (1938)), or to its local accumulation in the tissues. Data bearing on these possibilities have been obtained from experiments involving artificial blocking of vessels. Details of these will first be considered before passing to the hormone mechanism. It has been shown earlier in this paper that bacteria are present, generally in blocking numbers, in some stem vessels of tomato, below the points where adventitious roots commence to develop and it appeared desirable to test whether mechanical blocking could induce root formation.

The conditions of bacterial blocking were found difficult to duplicate as any attempt to block the xylem vessels involved interruption of at least the external phloem. This difficulty was partly obviated by combining experiments involving interruption of xylem and phloem by cutting, with others in which blocking substances were introduced into the xylem after cutting. The cut stems served in the sense of controls to the cut and blocked stems. A positive result was obtained, as in several experiments roots developed for over 1 inch both above and below cut bundles blocked with such substances as cocoa butter, lanoline and paraffin wax-vaseline mixture, while in the control plants where only cutting was practised, adventitious roots were found to develop only in the immediate vicinity of the cut. In experiments reported earlier on mechanical blocking in relation to epinasty (Grieve, 1939) positive results were obtained in only three out of 40 experiments. It is of interest to note that further examples of epinasty induction by blocking were recorded in the present experiments, but the condition was not found to be constantly associated with the experimentally induced adventitious roots.

The results obtained in these blocking exeriments point to the possibility that where the invading bacteria are present in large numbers sufficient to block some of the vessels, the blocking effect may be an important factor in root formation. However, until a method of blocking the vessels with inactive substances without interfering with the phloem is developed, judgment must be reserved as to the closeness of the parallel and the importance of mechanical blocking.

The formation of adventitious roots above a cut on a stem has been explained on a plant hormone basis, as being due to the prevention of longitudinal transport of growth substance or root substance (Boysen-Jensen, 1936) and this explanation would appear to apply also in the case of the cut stems of tomato. In the cut and blocked bundles, the additive effect recorded may be explained either by envisaging a heightened production of growth substance in the vicinity of the affected parts or an accumulation of growth substance coming from other parts via either xylem or phloem. The first hypothesis appears to fit better the fact that adventitious roots form in the blocked region below a cut.

While as indicated above, caution must be exercised in making too close a parallel between the cutting and blocking of bundles of stems and the bacterial blocking of xylem, yet the results obtained, taken with the negative results for heteroauxin formation in the vessels, make it probable that the stimulation effects are due to an increase in local concentration of growth substance produced by the host cells which concentration is brought about by the presence of the parasite.

Disturbance of xylem-phloem relations by blocking of vessels and the accumulation in them of metabolic products (which are non-active physiologically) may both contribute to the increase in growth substance content leading to the formation of adventitious roots.

Summary.

1. A detailed account has been given of the development of adventitious roots in plants infected by *Bacterium solanacearum*. Comparisons have been made with similar effects induced by *Bacterium tumefaciens* and *Aplanobacter michiganense*, by synthetic growth substance (heteroauxin), by wounding and blocking of stems and by the influence of gravity. The relation of the invading bacteria to the developing roots was established by transverse and longitudinal sections, showing that the root primordia commenced development ahead of the advancing columns of bacteria in the vessels. Development continued to the nodule stage even though the bacteria filled most of the vessels behind the root primordium.

2. Results of ether extractions gave no significant difference in the growth substance content of healthy and invaded stem parts. Nevertheless the close parallel between the formation of adventitious roots in infected plants and by synthetic growth substance, indicated that growth substance was associated with the adventitious root primordia. The question as to whether the active substance inducing the roots is produced by the pathogen or the host cells is discussed. The evidence so far available indicates that it is more likely that the stimulation effects are due to the increase or accumulation of plant hormone under the influence of the invading bacteria, rather than to a direct product of bacterial metabolism.

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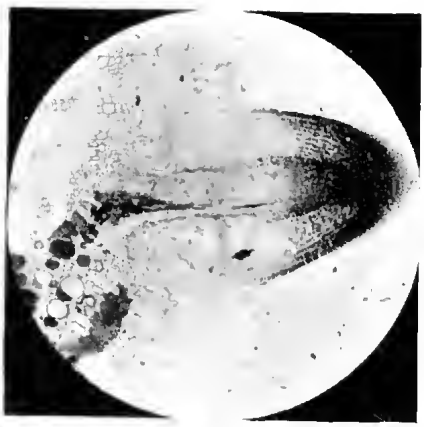

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Explanation of Plate.

Plate XVI

Fig. 1.—Infected tomato plant showing outgrowth of adventitious roots in humid air.

Fig. 2.—Adventitious roots induced in *Tagetes erecta* on infection by *B. solanacearum*.

Fig. 3.—Production of adventitious roots in *Tagetes erecta* after uptake of growth substance extracted from media in which *B. solanacearum* had grown.

Fig. 4.—Tomato stems infected by *B. solanacearum* showing outgrowth of roots when the cut bases are placed in water.

Fig. 5.—Transverse section of a developing adventitious root on an infected tomato stem. Note the presence of bacteria in the vessels leading to the vascular system of the new root.

[Proc. Roy. Soc. Victoria, **53** (N.S.), Pt. II., 1941.]

Art. XII.—*Studies of the Varieties of Subterranean Clover.*

By YVONNE AITKEN, M.Agr.Sc., and
F. R. DRAKE, B.Agr.Sc.

[Read 14th November, 1940; issued separately 26th July, 1941.]

Introduction.

The Type Variety of the Species in Australia, and its Variation—Phenotypical and Genotypical.

Polymorphy within the Species and Comparison with other Species.

Discussion of Major and Minor Characters.

Origin of Varieties.

Relation of Time of Sowing to Growth and Reproduction.

Observations on Productivity in Relation to Variety and Environment.

Introduction.

In Australia, the occurrence of varieties within the species of *Trifolium subterraneum* was first noted by Adams of Muresk College, Western Australia in 1924, and several varieties were described by him from 1924 to 1934 (1–7).

In Victoria, on the initiative of Mr. J. E. Harrison of the Department of Agriculture, a few samples obtained from each of the southern states of Australia were grown for observation in 1928. This preliminary work showed that a wide diversity of types existed and indicated the necessity for making a more extensive collection. This was arranged by Mr. Harrison, and largely with the assistance of district dairy supervisors of the Victorian Department of Agriculture, a State-wide collection was assembled in the summer of 1928/29. Officers were requested to collect samples from fields in which the clover had appeared voluntarily, rather than from fields which had been sown with commercial seed. This procedure, which was based on the knowledge that most commercial seed was of the one type, was adopted in order to overcome the possibility of assembling too cumbersome a collection, without reducing the collection of lots likely to show differences. With the addition of further samples from Western Australia, South Australia, Tasmania and the United States of America, 143 lots were grown in 1929. To these were added collections from Europe and New Zealand in 1930 and 1931, while new samples from Australian sources have been collected since and grown each year.

In 1929, owing to the absence of Mr. Harrison, the first large collection was examined and classified by Mr. F. R. Drake of the Victorian Department of Agriculture, who continued his observations on selected units of this and other collections in the following years.

The most noteworthy feature of the first and subsequent collections was the remarkable uniformity shown by the plants grown from any one sample. In only eight lots of the first large collection was there any marked lack of uniformity and even these consisted of a mixture of only two or three distinct types. Approximately half of the same collection proved to be of the standard commercial type, generally described as a mid-season type or "Mt. Barker." The remaining lots, which included some very extreme types, differed from this standard type in one or more characters and provided sufficient material for a classification into early, mid-season, and late flowering strains (Plate XVIII). Differentiations were made within each of these groups according to minor variations in dates of flowering, and to such characters as habit of growth, location of first flower on the runners and colour or markings of stem, leaf, flower and seed. On this basis 39 strains were separated and noted in 1929, and though fresh collections have added to this number from time to time, the 1929 collection proved to be the largest and most fruitful source of variable material. The strains have been grown as separate plants in adjacent plots from year to year, and have exhibited an extreme stability of type. The practical aspect of the wide variations between strains has commanded most attention, and has led to the commercial development of a few very promising pasture strains.

In 1936, Miss Y. Aitken began a study of the subterranean clover collections, in order to formulate a scientific record of the strains which had been isolated, and to study their response to such environmental factors as length of day, temperature and saturation deficit.

The Type Variety of the Species in Australia, and its Variation, Phenotypical and Genotypical.

In Australia the most widely spread variety is that known as Mt. Barker. A description of an individual plant grown under standard conditions (fig. 1), and of its capacity for phenotypical and genotypical variations, gives a basis on which the known polymorphy of the species can be recorded and analysed; such a description is as follows.

A prostrate, villous, annual plant with a short main axis and strong lateral growth.

Seedling.—Epigeal, cotyledons glabrous, 5 mm. long, their stalks twice as long as their oval blades.

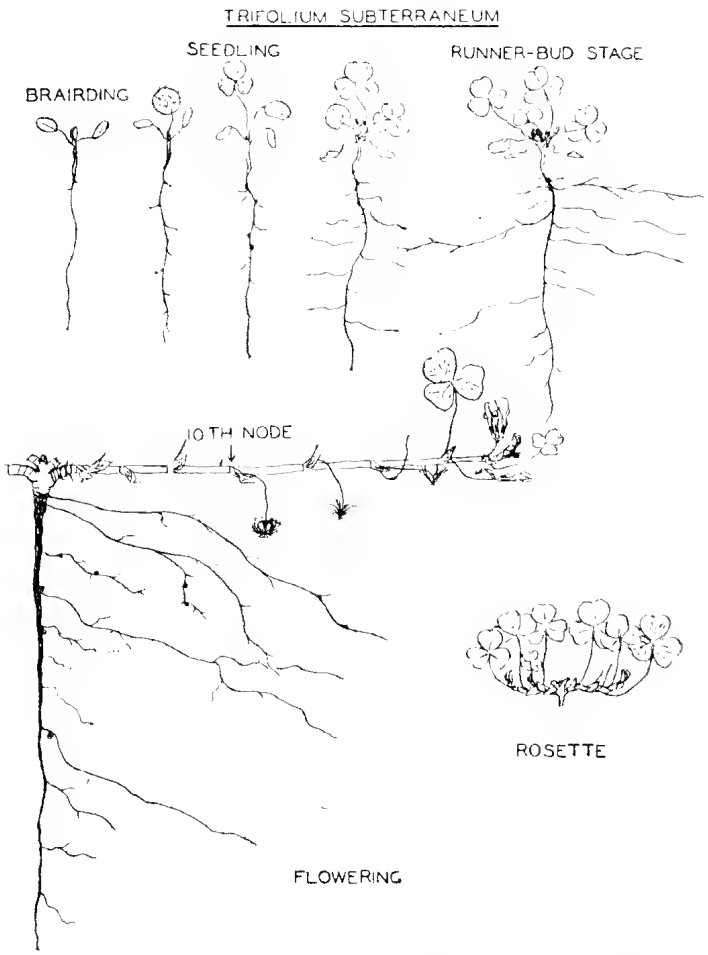

FIG. 1.—Stages in the development of a plant of *T. subterraneum* —variety "Mt. Barker".

Growth and flowering.—Each plant develops about five basal leaves, and then grows into its winter phase the rosette state, then from the basal nodes, about five prostrate runners are produced, each of these runners has about three nodes. In late winter with the onset of flower development (fig. 2*a*), the youngest internodes of the runners elongate slightly, while secondary laterals begin to develop from the basal nodes of the runners. By early September, the internode proximal to the first flowerhead elongates conspicuously, and by mid-September, the first flowerheads open. These develop at about the tenth node of each runner. Later, axillary flowerheads form at the more distal nodes and also occur on the secondary laterals. Towards the end of the flowering period,

after about nine flowerheads have formed along the runner, the later-formed internodes and peduncles are dwarfed, and few of the corresponding flowerheads form viable seed. After the formation of about sixteen runners, flowering at the top of the main axis prevents further runner initiation. According to Wexelson (25) the chromosome number in the vegetative stage is 16.

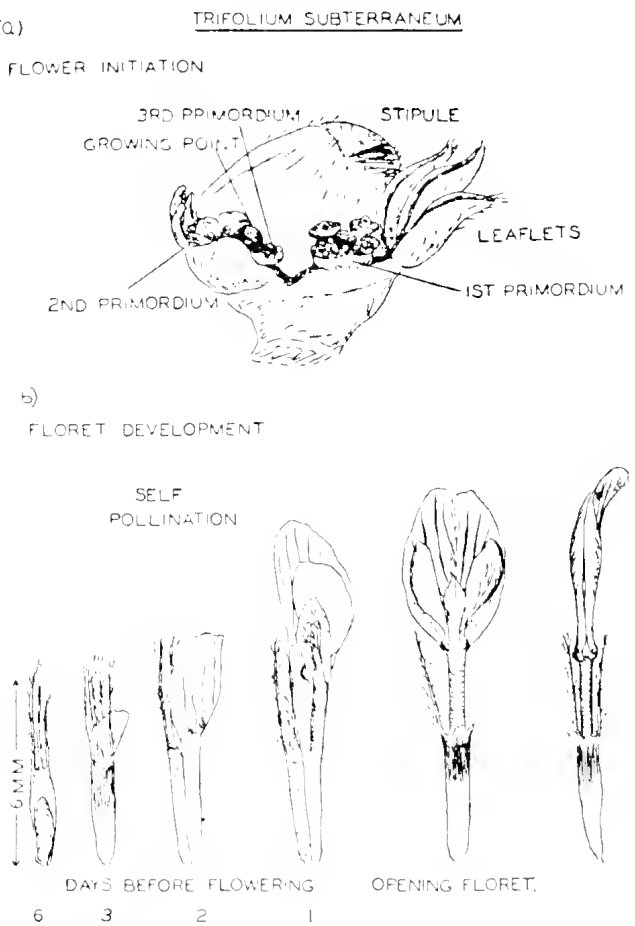

FIG. 2.—Growth of the flower (*a*) the tip of a runner, dissected to show the flower primordia, shortly after initiation; (*b*) the appearance of a floret, several days before and after self-fertilization.

Leaves.—First leaf simple, villous, about 9 mm. long and 12 mm. broad, its base almost straight; later ones ternate, leaflets obcordate, villous on both surfaces, green with local brown flecks due to anthocyanin in the upper epidermis. Centrally across each leaflet is a pale green crescentic area, which becomes less conspicuous in the late flowering stage. The petiole is villous,

and four or more times longer than the leaf. The stipules are more or less villous, ovate-acute, attached in their lower halves to the petiole, typically red-striped over the veins and often red between the veins also.

Stems.—The stems of the runners are villous, and green turning to brownish in spring, with exposure to sunlight as the internodes lengthen.

Inflorescence.—Flowerheads axillary, each with three to five perfect florets, peduncle 1.5 cm. long. Floret about 12 mm. long; calyx tubular, yellowish below, red on half to two-thirds of the upper part of the tube with five green, narrow, free setaceous lobes a little longer than the tube; corolla white, with faint pink veins on standard and alae; standard three times as long as the calyx tube. Self-fertilized, pollination occurring when the tip of the folded corolla is at the level of the tips of the calyx lobes (fig. 2*b*). The standard and alae expand fully two days later, and then the corolla withers, the pedicels become reflexed while the distal region of the peduncle becomes positively geotropic and bends down to the ground and lengthens up to 4–5 cm., thus forcing the developing fruits into the ground if soft. The peduncle tip forms a succession of four- or five-rayed to simple pronglike growths which are, morphologically, sterile and partly-developed flowers, these turn upward round the developing fruits and thus form the burr characteristic of the species. Each burr usually contains three to four seeds. Ovary with two anatropous ovules, only one developing to form a one-seeded fruit with a brown, membranous wall.

Mature seed.—Purplish-black, dull-surfaced, oval except for the radicle notch, $1\frac{1}{2}$–$2\frac{1}{2}$ mm. long.

The characters entirely specific in the genus to *T. subterraneum* are (1) an inflorescence of very few perfect florets (2–5); after fertilization (2) the development of many spur-like sterile florets and (3) the occurrence of elongation and positive geotropism in the peduncle.

Polymorphy within the Variety.

Phenotypical variation in such environmental factors as light intensity, temperature, competition and disease incidence may alter the appearance of the plant in several ways.

(*a*) Internodal length, the number of laterals along a runner, and the number of runners may be reduced by competition (see fig. 3*a*; Plate XVII., fig. 2) by insufficient water or nutrients or by disease. A small, sparse-leafed plant results. Extreme conditions reduce the rate of node formation.

Other things being equal, the date of germination influences the position at which the first flower is produced on the basal runners, and also the development of laterals (fig. 3*b*).

(*b*) The length of petiole and the size of leaves are also reduced by insufficient water-supply and by disease.

(*c*) The brown flecks and shading on the leaves and stem surfaces are prevented or reduced by shading from direct sunlight, or by mosaic infection. Attacks by the red spider cause a general red appearance of the leaves; while phosphate deficiency results in a purplish brown colour.

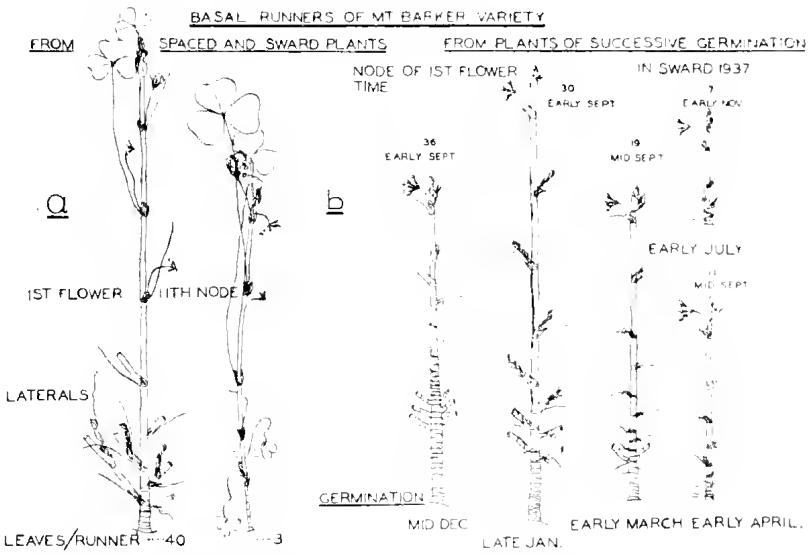

FIG. 3.—Basal runners of "Mt. Barker" variety, showing (A) the effect of sward, and spaced conditions, on lateral and leaf production; (B) the effect of date of germination in a sward, on lateral production, and on the node at which the first flower was produced.

Other abnormalities such as a marked dwarfing of the plant and a conspicuous reddening of the leaves have occasionally been noted, but not yet investigated.

Genotypical variations within the type variety are few owing to the close selfing of each plant. Probably the strains "White-Seed" and "Amber-Seed," may be regarded as variations due to a bud-mutation, preventing the development of the usual purple-black colour of the testa and of other anthocyanin markings in leaves, stem and flower. Such a bud-mutation certainly occurred on a plant of the variety Dwalganup when a burr with white seeds was found on a runner bearing burrs with normally coloured seeds. The following year the white seeds produced plants of the Dwalganup type but without anthocyanin in any part. "White-Seed" and "Amber-Seed" differ similarly from "Mt. Barker" and so also does a white seeded plant which

occurred in the 1940 plot of the variety "Bass." Variations from the normal recorded in the following section, may be due to similar mutations though no direct evidence has yet been found.

Polymorphy within the Species.

This survey of the hereditary variation within *T. subterraneum* shows a close similarity with that found in other closely-studied species of the Leguminosae. In Table 1, the variation of homologous characters of *T. subterraneum* is compared with those of *Pisum sativum* and *Vicia sativa*, after the plan of V. Muratova (17) and with the use of his data on *Vicia sativa* and with local data on *P. sativum*. Agriculturally it is particularly significant that forms occur with wide variations in respect to such important vegetative characters as length of vegetative period, lateral formation and size of leaf.

It should be noted also, that the record of variations within the other two species are the result of the study of an exhaustive world collection, whereas that for *T. subterraneum* is based mainly on Australasian types. Hence the similarity in homologous variation may be expected to become even closer when more European forms have been collected and studied.

At Burnley Gardens, Melbourne, observations of the various samples grown under the same conditions year after year, have shown that more than 50 varieties exist. Each variety differs from the rest by at least one distinct character. Table 2 lists the main characters of each variety.

Discussion of Major and Minor Characters.

Major Characters.

Major characters are those responsible for the detailed growth form and biological efficiency of the plant. These are:—

1. Number of runners per plant.
2. Lateral development (number of laterals per runner and degree of branching).
3. Internode length.
4. Leaf size and petiole length.
5. Number of seeds produced.

The number of runners per plant, the number of laterals and their degree of branching (figs. 4*a*, *b*) are strongly influenced by the inherited character of time of flowering, which may be considered to be an inter-related major character (Plate XVIII). The numerical production of stem growths (runners and laterals), which depends on these characters, largely determines the plant's capacity for the production of leaves and seed, as in the axil of each leaf a vegetative shoot or a flower may be produced. The four or five first produced, or "basal" runners

TABLE 1.—LIST OF THE HERITABLE CHARACTERS KNOWN TO OCCUR IN *T. subterraneum*, *Vicia sativa* and *Pisum sativum*.

		T. sub.	Vicia sativa.	Pisum sativum.
FRUIT—				
Size	small	..	..	−
	medium	+	+	−
	large	+	+	+
Number of Seeds	1	+	..	..
	2	+	..	..
	3–6	..	+	+
	7–12	..	+	+
SEED—				
Colour	white	+	+	−
	yellow	..	+	+ (12)
	green	..	+	−
	grey	..	+	−
	dull brown	+	+	−
	red brown	..	+	−
	brown	..	+	−
	black	+	+	+
Size	small	..	..	−
	medium	+	+	−
	large	+	+	−
FLOWER—				
Corolla Colour	white	+	+	−
	yellow	..	+	..
	pink	+	+	−
	purple	..	+	−
	violet	+ (19)	..	..
Calyx Colour	green	+	+	−
	with anthocyanin	+	+	−
INFLORESCENCE—				
Number of Flowers	1	..	+	+
	2–3	+	+	−
	4–7	+	..	..
VEG. CHARACTERS—				
Formation of Laterals	feeble	+	+	−
	strong	+	+	+
,, ,,	in axils of basal leaves	+	+	+
	scattered	+	..	..
STEM—				
Stem	long	+	+	+
	medium	+	+	−
	short	+	+	−
,,	pubescent	+	+	..
	glabrous	+	+	+
LEAFLET—				
Diameter	10–15 mm.	+	..	..
	15–25 mm.	+	+	+
	25–30 mm.	+	+	−
	30–40 mm.	..	+	..
Colour	anthocyanin	+	..	−
	none	+	+	−
Petiole	glabrous	+	..	−
	pubescent	+	+	..
Petiole	anthocyanin	+	..	−
	none	+	+	−
Stipule	anthocyanin	+	+	+
	none	+	+	+
,,	glabrous	+	+	−
	pubescent	+	+	..
BIOLOGICAL CHARACTERS—				
Vegetative period	early	+	+	+
	late	+	+	+

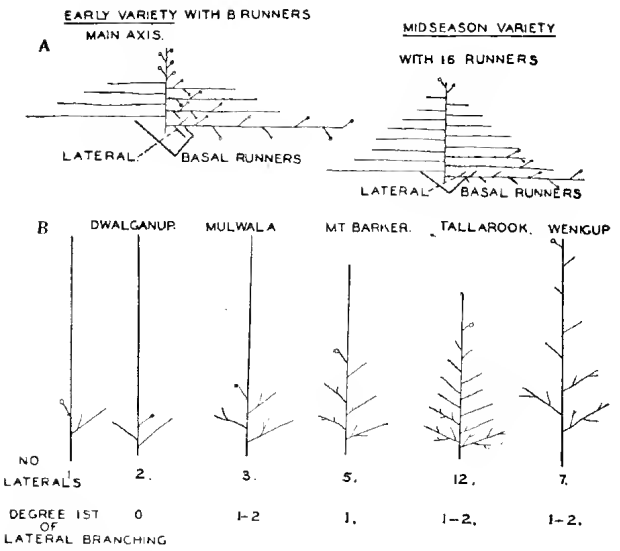

FIG. 4.—Diagram to show (*a*) the relation between the number of runners produced per plant, and the time of flowering (maturity) of a variety (main axis much lengthened); (*b*) types of runner structure, resulting from variations in number of laterals and degree of branching.

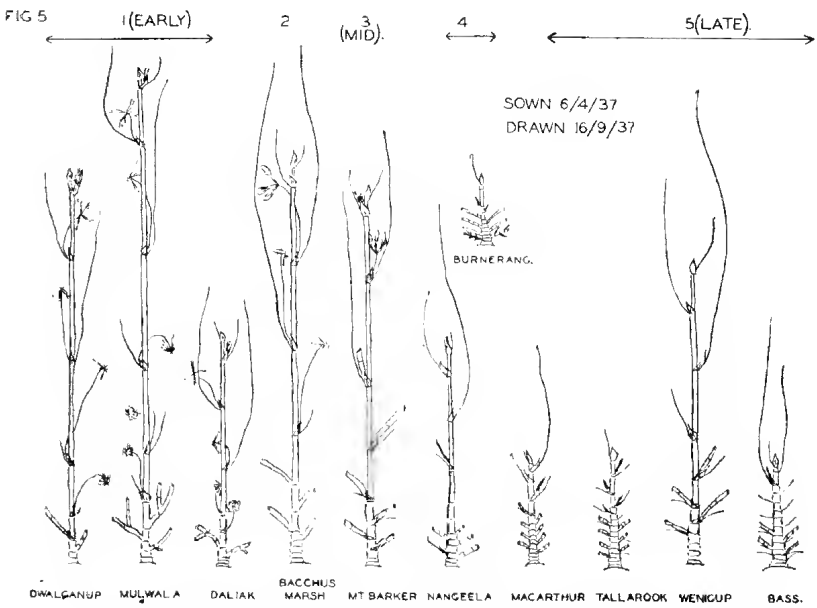

FIG. 5.—Typical basal runners of varieties sown in early April, and drawn in mid-September (laterals are not drawn in detail).

of a plant have been taken as typical, and observations and measurements confined to them. The combined effect of the major characters as above (except number of runners per plant) results in what may be termed a "basal runner organization" typical of each variety (fig. 5; Plate XVII., fig. 2).

1. Characters of the Basal Runner.

Time of flowering is a variable character influenced by time of germination, but if all the varieties are started together the relative time of flowering constitutes a reliable expression of the length of the vegetative period of each variety. As the rate of node formation per runner is approximately the same in all varieties during active growth, except towards the end of flowering, it follows that time of flowering determines the node on which the first flower is formed along the runner. This in turn determines the capacity of the variety for lateral formation, as lateral shoots only develop below the first flower of a runner. Time of flowering is also related to the time of commencement of internode elongation, and the length of internodes during flowering. At Burnley, the date of commencement of flowering in the varieties ranges from early August to late October, but flowering dates coincide for many varieties, and for the sake of convenience the varieties may be separated into early, early mid-season, mid-season, late mid-season and late groups.

In Table 2, the varieties are listed from left to right in order of time of flowering. Reference to lines 26 and 15 shows that the number of the node on basal runners at which the first flower is formed, and the number of laterals per runner, increase with later flowering; while the internode length (line 14) following the fourth flower along the runner, tends to decrease. This character-complex is bound up with the photoperiodic response of the plant, which will be discussed later.

2. Development of Laterals.

This varies both in respect to their number and their degree of branching. Increasing lateness of flowering (as in (1) above) causes a range from 4th to 20th in the nodal number of the first flower, and from 1 to 16 in the number of laterals per runner. The first two or three, and sometimes more nodes, do not produce laterals, with the result that within the same time of flowering there is variation in number of laterals produced. The degree of branching of the laterals tends to increase with lateness of flowering (fig. 4*b*) and here again there is variation within the same maturity groups. Thus choice is possible of the most productive variety for a given length of growing season.

The variety Mulwala develops two or three double branching laterals per runner, but Dwalganup forms only one or two simple laterals. Tallarook with about ten laterals branching to the second or third degree differs markedly from Wenigup, with

only about five unbranched laterals. Burnerang has an extreme capacity for lateral formation and branching, even compared with the latest varieties.

3. The Commencement of Internode Elongation.

This occurs in the terminal internode at the same time as flower initiation at the growing point, but it is usually slight till the internode before the appearance of the first flowerhead, when the internode is from three to six times longer than the basal one. In consequence, though flower initiation in the varieties ranges from late May to early September, the conspicuous lengthening of runners does not begin till one or two weeks before flowering, except in two late varieties, "Rostock" and "Wenigup." In these, conspicuous elongation occurs more than a month before flowering. The length of the internode above the fourth inflorescence along the main stem of a basal runner is taken as a measure in line 14, of Table 2, because this was found to be the most satisfactory index of this character. The length of internodes at flowering, varies from about 5 cm. in the early varieties, to less than 2 cm. in the late ones. This results in the "stemmy" appearance of most of the early varieties compared with the increasingly compact later ones. In addition, the increase of laterals and hence leafiness, emphasizes the contrast. Three exceptions are "Daliak"—a compact early variety with short internodes, and short-stalked, small leaves, and Wenigup (Plate XVIII., fig. 12) and Rostock—"stemmy" late varieties with extremely long internodes and long-stalked, large leaves. The variety Burnerang is unique in its "bunched" appearance, which is due to a combination of extremely short internodes, both before and after elongation, and very profuse lateral-formation and branching. This results in the compressed laterals bending upwards and thus raising of the leaf level in the middle of the plant (Plate XVIII., fig. 15).

4. Leaf Size and Petiole Length.

The length of petiole and size of leaf tend to decrease with later-flowering varieties, but Wenigup and Rostock are exceptions in the late group, and Daliak in the early group.

5. Number of Seeds Produced.

The number of seeds formed per flower cluster, varies normally from three to four, but in "Reigert's White-seeded," normally only three flower primordia are initiated and develop into three-flowered clusters which ripen three large seeds. In Wenigup the flower primordia vary from two to four and two to three seeds are usually formed. In Burnerang, a high percentage of "twin" seeds are formed from the equal development of the two ovules in one or two ovaries of each cluster, resulting in four or five seeds per burr.

Minor Characters.

In addition to those variations in the above characters, which are regarded as having an important bearing on their agricultural significance, the varieties usually differ in minor characters such as anthocyanin development, leaf crescent, density and pubescence, etc. The varieties are still named after the district from which each was first collected, even though other varieties may occur in the same district. Exceptions have been made for several varieties which differ from one or other of the district varieties only in a minor character, which can be indicated in the name, e.g. Pink flowered, Red leaf (Plate XIX., fig. 1), White seeded and Amber seeded.

The existence of a record of character combinations should obviate any confusion associated with locally named varieties. It is interesting to note the amount of variation already found in some characters. Anthocyanin development in the leaf lamina may vary widely in amount, and its location may be any one of the types shown in fig. *6b*. In the stipule (fig. *6c*), it may be absent or may cause red striping over veins or diffuse red areas. In the stem it causes a brownish green to dark brown appearance according to the number of epidermal cells affected; in the corolla, pink-veined white florets to dark pink ones; in the calyx (fig. *6d*) a pink or brown tipped, or red-banded to red calyx tube; in the seed a black testa; in the germinating seedling (fig. *6e*), a brown band on the hypocotyl. Its occurrence on the leaf may not be linked with its presence elsewhere, e.g. in the variety "Reigert's White-seeded" where it occurs conspicuously in all parts of the plant, except the seed testa. Conversely, absence of anthocyanin from all vegetative and floral parts is linked in several cases with a colourless testa, "White-seeded Dwalganup" and white and amber-seeded forms of "Mt. Barker."

The central pale green area, known as the "leaf crescent" in Mt. Barker, is absent from some varieties and in others varies from a central dot to a crescent stretching to the leaf edges (fig. *6a*). It may be combined with the character causing white arms in the crescentic area (fig. 6, C4) in which case, the leaf crescent is very conspicuous (Plate XIX., fig. 2). The white area on the leaf surface is caused by the presence of air below the epidermis, which is separated locally from the palisade layer.

The combination of a leaf crescent with anthocyanin modifications, makes distinctive leaf markings for certain of the varieties, e.g., in Dwalganup, Second Northam, Reigert's White-seeded, Bacchus Marsh, Mt. Barker, Nangeela, Macarthur, Tallarook, etc.

The degree of hairyness is of special interest as so many of the early descriptions of the species describe it as "very hairy" (Table 3). Certain of the early flowering varieties are pubescent over all vegetative parts, and the length, density, and laxness of

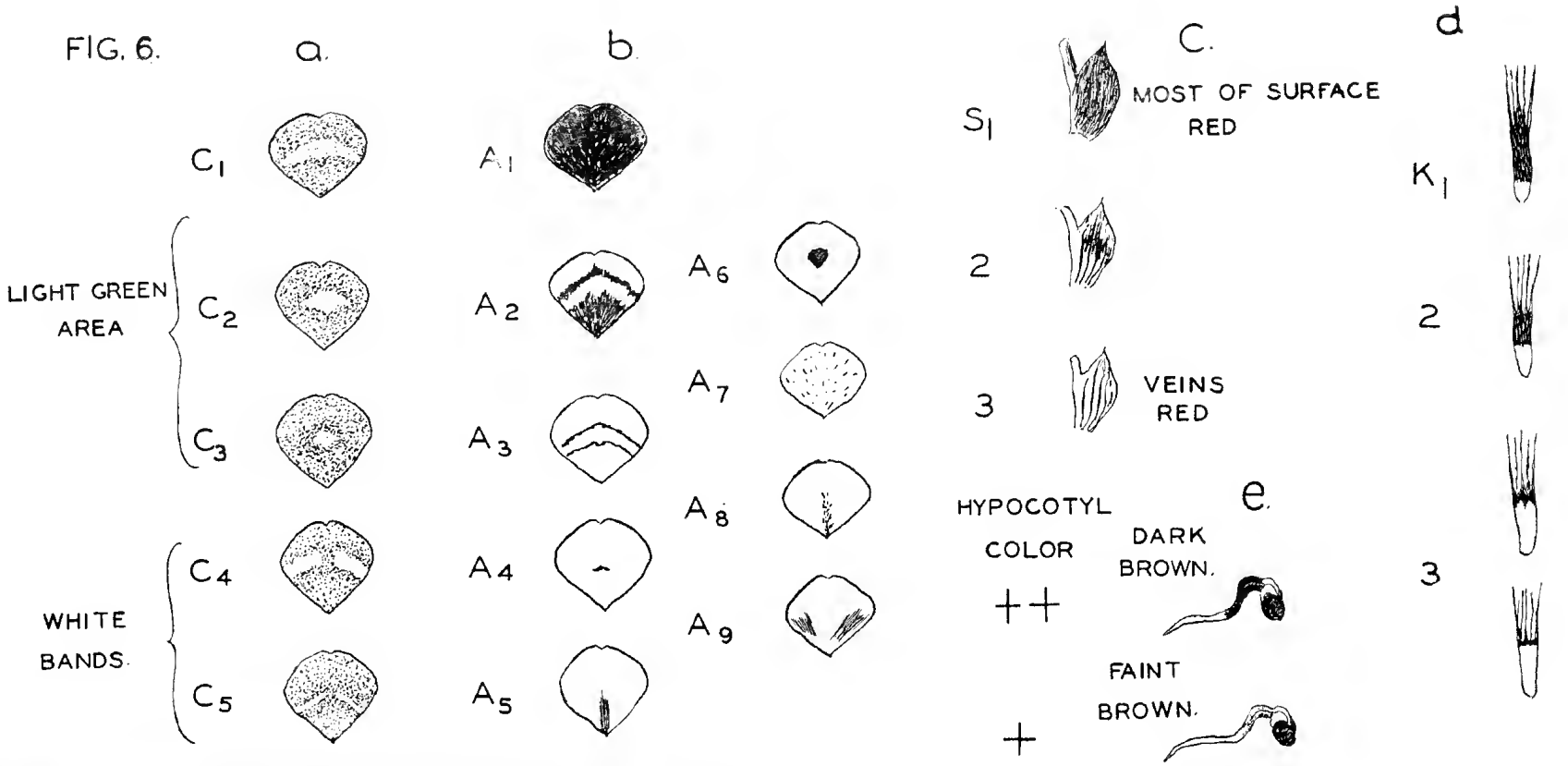

FIG. 6.—Inherited variations in the anthocyanin developed on leaf, stipule, calyx, and hypocotyl.

Table 2

← E. → ← E.M. → ← M. → ← L.M. → ← L. →

				DWALGANUP	WHITE SEEDED DWALP	MURESK	2nd NORTHAM	MULWALA	DALJAK	NORTHAM	REIGERT'S WHITE	PINK FLOWERED	YABBA N.	SPRINGHURST	SEATON PARK	BACCHUS MARSH	BURNLEY	MADRID	MILTON	HORSHAM	HILL'S SMALL	SAMARIA	YEA	EDENHOPE	MT. BARKER	WHITE SEEDED MT. B.	AMBER SEEDED MT. B.	RED LEAF	SMEATON	CASTERTON	HEXHAM	MANSFIELD	DERRINAL	BENALLA	BERLIN	WANGEELA	KYABRAM	BURNERANG	PAHANTAMU	MERINO	MACARTHUR	RUAKURA SEL^{n}	TAILAROOK	WENIGUP	ROSTOCK	FLINDERS	MODONGA	RCUEN	PHILIP ISLAND	KYNETON	GASS	BASS WHITE SEEDED	KUAKURA FARM
1	LEAF	COLOUR of LAMINA	Grey Green	+	+	+	+	+		+		+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2			Mid-Dark Green						+		+				+													-																								
3		PATTERN	Pale Central Mark	C3 5	C3 5	C3 5	C1 2	C3 5	-	C1	C4	-	C1	C3 5	C3 5	C1	C3 5	C3 5	C1	C1	C2	C1	C1	C2- 1	C2	C2	C2	-	C3 4	C3 5	C1	C2 1	C3 5	C1 5	C1 2	C1 5	C2 4	C1 3	C2 3	C1 7	C2	C3	C3 5	C3 5	-	C1	C1 2	C1	C1	C1 2	C1	C2	C2	C1
4		of	Anthocyanin Upper Sur.	A2 7	-	A5	A3	A5	A7	A2	A2	A7	A2 7	A2 7	A4	A7 B	A7	A2 7	A7	A7	A5	A5	A7 5	A5 7	A5	-	-	A1	A6	A5 7	A7	A3 B	A7	A2 7	A7	A7	A5 7	A7	A2 7	A7	AB	A7	A2 7	A7	A2	A5 7	A2 7	A2	A2 7	A2	A2	-	A2 7
5		LAMINA	Anthocyanin Lower Sur.	A6 7	-	-	A7	-	A7	A6	A9	A7	A7	A6 7	-	A7 B	-	A9 7	-	-	-	A7	A6 7	A7	-	-	-	A1	A6	A6 7	A7	A6	A7	A7	A6	A6	A6 7	A6	A7	A7	-	-	A6 7	A7	A7	A7 9	A7	A6 7	A6	A7	A6	A6 7	-	-
6		HAIRINESS	Upper Surface	++	++	-	++	++	+	+	F	+	++	+	F	+	F	+	+	+	+	+	F	+	+	+	+	-	+	+	+	+	+	F	+	+	+	F	F	+	+	+	-	F	F	F	F	+	F	F	F
7			Lower Surface	++	++	++	++	++	+	+	+	+	++	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
8		*SIZE	Diameter of Leaflet	S	M	S	M	M	S	S-M	L	M	S-M	M	M	L	L	L	M	S	M	M-L	M	M	M	M	M	M	M	L	M	M	M	M	S	L	M	M	L	M	M	M	M	M-L	L	S-M	M	M	S-M	S-M	M	M	M
9			*Length	M	M	M	M	M	S	M	M	M	M	M	M	L	L	L	M	M	L	M	M	L	M	M	M	M	M	M	M	M	M	M	M	S	M	M	M	M	M	M	M	S	M	M	M	M	S	M	M	M
10		PETIOLE	Colour	B	G	B	B	B	Gb	Bg	B	B	Gb	B	B	Bg	Bg	Bg	Bg	B	Gb	Gb	Gb	B	B	G	G	Bg	B	B	G	Gb	B	B	G	G	G	B	G	B	-	B	G	B	B	Gb	Gb	Gb	B	G	Bg	G	B
11			Hairiness	+	+	F	++	+	F	+	-	+	-	+	+	+	F	F	+	+	+	+	F	+	+	+	+	+	+	+	+	+	+	F	+	+	+	+	+	+	F	F	F	-	+	F	+	+	+	+	F	+	F
12		STIPULE	Colour	S3	-	S2	S3	S3	S1	S3	S1 2	-	S3	S3	S3	-	S2	S3	-	-	S3	S2	S2	S2	S2 3	-	-	S3	S3	S3	S3	S3	S3	S2	S3	S3	S3	S3	S3	S3	S3	S3	-	-	S3	-	-	S3	S3	S3	S2 3	-	S2 3
13			Pubescence	F	+	F	+	F	+	+	-	F	-	+	+	+	+	+	+	F	+	+	+	+	+	+	+	+	+	+	+	+	+	F	+	+	+	+	+	+	+	+	F	F	-	F	F	+	F	F	F	+	F
14	*	INTERNODE	Length above 4th Flower	L	L	L	L	L	M	L	L	L	M	L	M	L	L	L	L	M	M-L	M-L	N	M-L	M-L	M-L	M-L	M-L	L	M	M	M-L	M	M	M	L	M	S	M	M	M	M	M	L	L	M	M	M	M	M	M	M	M
15	*	LATERALS	Number per Runner	1-2	1-2	1	2	3	2	2	2	1-2	4	2	2	3-4	4-5	3-5	6	4	5-7	4	5	5-7	5	3-5	3-5	3	4	7	7	12	L	6	9	8-12	11	12	7	6-7	10	L	12	M	L	10	12	11	15-16	14	B-9	8-9	11
16			Degree of Branching	0-1	1-2	1	1-2	1	1	1	2	0-1	1	1	1	1-2	1-2	1	1	1	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	2-3	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2	1-2
17	*	RUNNER	Number per plant	S	S	S	S	S-M	S	S	S	S	S	S-M	S	M	M	M	M	M	M	M	M	M	M	M	M	M-L	M	M	M-L	L	M	M	M-L	M-L	M	L	L	L	M	L	M	M-L	L	L	M	L	L	L	L	L	L
18	STEM		Colour	B	B	B	B	Bg	B	Bg	B	Bg	Bg	B	B	Bg	Gb	Bg	Bg	B	Gb	Bg	B	Gb	B	G	G	G	B	B	Bg	Bg	Gb	B	Gb	G	B	G	Gb	Gb	Gb	G	Gb	+	+	B	Gb	+	+	Bg	G	Gb
19			Pubescence	++	++	++	++	++	F	+	-	+	-	+	+	+	-	-	+	+	+	+	F	+	+	+	+	+	+	+	+	F	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
20			Thickness			*	*									M		S							M														M-L	M														
21	FLOWER		Corolla Bud	P	W	P	W	P	W	P	W	R	P	P	W	W	W	W	W	W	W	W	W	W	W	W	P	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
22			Open Corolla	P	W	P	W	P	W	P-W	W	R	W	W	W	W	W	W	W	W	W	W	W	W	W	W	PT	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
23		COLOUR	Calyx Tube	K4	-	K2	K2	K4	K1	K3-4	K4	K4	-	K4	-	-	-	-	-	K2	K2-3	K3	K3	K2	-	-	K3	K3	-	K3	K3 4	K3	K3	K3	K3	K3	K3	K3	K3	K3	K3	-	-	-	K3	-	K3	K2 3	K3	-	-	K3
24			Calyx Lobes	B	G	B	G	B	G	B	B	B	G	B	G	BG	G	B	G	BG	G	G	G	GB	G	G	G	G	G	G	G	G	B	GB	G	G	G	G	G	G	G	GB	G	G	BG	G	GB	G	GB	G	G	G
25		Pubescence Calyx Tube		F	F	F	+	F	F	+	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	-	-	-	-	-	-	-	-	-	-	-	-	F
26		Node of 1st Flower		4-5	4-5	4-5	5-6	4-5	4-6	6	7	5-6	8-9	5-6	6-7	7-8	8-9	9	9	9	9	B-9	8-9	9-10	9-11	11	10	10	12	11	11	14	13	11 12	11 12	13 14	15	13	12 13	13	13	15	16 17	15 16	16 17	16	16	16 17	17 1B	15 16	17 19	17 19	1B 19
27		Time of 1st Flower		MID-AUGUST					LATE AUGUST							EARLY SEPTEMBER							MID-SEPTEMBER							LATE SEPTEMBER											EARLY			MID-OCTOBER						LATE				
28	SEED		Colour	Pp	W	Pp	Pp	Pp	Pp	Pp	W	Pp	B	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	W	B	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	W	Pp
29	SEEDLING		Hypocotyl Colour	++	-	++	++	++	+	++	++	++	-	++		+	+	+	+		+	+	+	+	-	-		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

TABLE 2A.

LEAF.

Hairiness of Lamina—
- — .. No Hairs
- F .. Few Hairs
- + .. Hairy
- + + .. Very Hairy

Fourth Leaf from Tip of Basal Runner—
Size—Diameter of leaflet—
- S .. 1 cm.
- M .. 1½ cm.
- L .. 2½ cm.

Length of Petiole—
- S .. 2 inches
- M .. 3–5 inches
- L .. 6 inches

STEM.

Length of Internode above 4th inflorescence of basal runner—
- S. .. ½ inch
- M .. 1 inch
- L .. 2 inches +

Number of Runners per Plant—
- S .. 5–11
- M .. 12–18
- L .. 19–25

Stem Colour—
- B .. Brown
- G .. Green

Stem Pubescence as for Leaf—
- * .. Appressed hairs

Stem Thickness—
- S .. Slender
- M .. Medium
- L .. Stout

FLOWER.

Corolla—
- W .. White
- W .. White with pink veins
- P .. Pink
- P.T. .. Pink Throat
- R .. Red

SEED.

Seed Colour—
- W .. White
- B .. Brown
- Pp .. Purple-black

TABLE 3.—VARIATIONS RECORDED FOR *T. subterraneum* IN EUROPE AND AUSTRALIA.

	Hairiness.			Stipule Pink Striped.	Leaf Pale Mark.	Leaf Dark Flecks.	Corolla Coloured.	Calyx Red Bands.	Node First Flower.	Time of Flowering.	Number of Varieties.
	Plant.	Leaf.	Calyx.								
ENGLAND.											
Curtis—London	+	+	..	+	..	+	−	+	2–3	June–Aug.	..
Smith	+	+	..	− +	..	..	..	..	..	..	..
Fitch and Smith	+	..	..	..	..	..	..	..	..	..	..
Hooker	+ +	+	..	..	..	..	−	..	1–2 ?	May–June	..
Trimen and Dyer—Middlesex ..	+	..	..	..	..	..	..	..	..	..	..
Bentham and Hooker	+	..	..	..	..	..	..	..	..	..	..
Avebury	+	..	..	..	..	..	−	..	2–3 ?	..	..
Sowerby and Smith	+	+ +	..	+	− +(white)	..	−	..	4–7	..	..
Sowerby and Syme	+	+ +	..	+	− +	..	−	..	4–7	..	..
Pratt	+	..	..	−	..	..	−	+	4–6 ?	May–June	..
Ray	..	..	..	..	..	..	−	..	..	..	..
Rees	..	+	..	+	..	..	..	..	..	..	..
Withering	+	+	..	..	..	..	−	..	..	..	..
Hooker and Arnott	+	+ +	..	..	..	..	−	..	..	..	..
J. Hill, Flore—Britain, 1760 ..	+	+	..	..	..	..	..	..	2–3 ?	..	..
Davies, W.—J Min. Ag., 1927 ..	+	+	..	..	..	− +	−	− +	..	..	..
FRANCE.											
Coste	+	..	..	..	..	..	−	..	..	..	..
Cosson and St. Pierre	+ +	+ +	+	..	..	..	−	..	..	May–July	..
Cosson and Germain Paris ..	..	+ +	..	..	..	..	..	..	..	..	..
Lamarck	+	..	..	..	..	..	−	..	..	..	..
Bonnier—N. France	+	..	..	..	..	..	..	..	..	..	..
Grenier and Godron W.F. Mid. F.	+	..	..	..	..	+ −	−	..	..	..	..
Spach—North France	+	..	..	..	..	..	−	..	..	..	..
Rouy and Foucard	+	..	..	..	..	..	−	−	..	..	..
GERMANY.											
Huth	+	+	..	..	..	..	..	−	1–2	..	..
Reichenbech	− +	..	+	−	..	..	−	−	6–7 ?	..	..
Hegi—Mid. Europe	+	..	..	..	..	..	−	..	..	..	..
SOUTHERN EUROPE.											
Boissier—Fl. Orient	+, + +	..	..	..	..	..	−	..	..	..	..
Linnaeus—France, Italy ..	+	..	..	..	..	..	..	..	..	..	..
Ascherson and Graebner ..	+, + +	+, + +	− +	..	..	..	+ −	+ −	..	..	4
De Halacsy—Greece	+	..	−	..	..	..	..	..	..	..	..
Willkomm and Lance—Spain ..	+, + +	..	..	−	..	..	−	..	..	..	..
Cocconi and Parna—Spain ..	+	..	+	..	..	..	..	..	..	..	..
Lazaro E. Ibiza—Spain ..	..	..	..	..	..	..	−	..	..	..	..
Fiori and Paoletti—Italy ..	+	..	..	..	..	..	−	− +	..	..	3
Bertolinii—Italy	+	..	..	−	+	..	−	−	..	..	..
Gay—Algeria	..	..	..	..	..	..	−	..	..	..	..
Post—Palestine	+	..	..	..	..	..	+ −	..	..	..	2
Ullman	+, + +	+, + +	..	..	..	..	+ −	+ −	..	..	5

TABLE 3.—VARIATIONS RECORDED FOR *T. subterranean* IN EUROPE AND AUSTRALIA—*continued.*

	Hairiness.			Stipule Pink Striped.	Leaf Pale Mark.	Leaf Dark Flecks.	Corolla Coloured.	Calyx Red Bands.	Node First Flower.	Time of Flowering.	Number of Varieties.
	Plant.	Leaf.	Calyx.								
SOUTH AUSTRALIA.											
Black, 1909	+	..	..	..	..	..	−	+	..	..	..
„ 1922	..	..	..	..	..	..	−	− +	..	Oct.–Dec.	..
WESTERN AUSTRALIA.											
Adams, A. B., 1927	++	+	..	..	− +	− +	−	− +	..	Aug.–Nov.	4
„ 1929	..	..	..	..	..	..	++	..	..	..	5
„ 1930	..	..	..	..	..	++	..	..	..	..	6
„ 1932	..	..	..	..	..	..	..	++	..	..	7
„ 1934	..	..	..	..	..	..	..	..	..	..	9
„ 1938	..	..	..	..	..	..	..	..	..	..	10
TASMANIA.											
Radel, 1935	++	+	..	−, +, ++	−, +, ++	−, +, ++	−	−, +, ++	..	Sept.–Oct.	9 (from Vic., S.A. and W.A.)
SOUTH AUSTRALIA.											
Donald and Smith, 1937 ..	..	..	..	..	..	..	..	..	..	Aug.–Oct.	14 (from Vic., S.A. and W.A.)
NEW ZEALAND.											
Levy and Gorman, 1937 ..	..	..	..	− +	..	..	..	− +	..	Aug.–Oct.	15 (from Vic., S.A. W.A.)
VICTORIA.											
Harrison, 1936	+	..	..	−	+ (white)	..	−	−	15	Oct.	1 Late
Drake, 1940	++	..	..	−	+	+	−	−	8	Sept.	1 E. Mid.
Aitken and Drake, 1940 ..	−, +, ++	−, +, ++	− +	−, +, ++	−, +, ++	−, +, ++	−, +, ++	−, +, ++	4–20	Aug.–Oct.	50 V. Early—V. Late.

the hairs on the upper lamina result in a greyish green appearance of the leaf (Dwalganup, Springhurst, Pinkflower). Other varieties are less densely hairy with mid-green leaves (Mt. Barker, Bacchus Marsh), while others have glabrous upper leaf surfaces, having some hairs or being completely without hairs on petiole, stem and stipule (Reigert's White, Wenigup, Burnley) (cf. Plate XIX., figs. 3–6). The presence of hairs on the lower surface of the leaf lamina is the only degree of pubescence held in common by all the varieties.

Origin of Varieties.

The list of varieties in Table 2, includes all the available ones isolated so far in Australia, and Appendix I. lists the areas from which each type (except Mt. Barker) has been obtained from 1929 onwards. So far the only indication of any particular area of concentration of varieties (cf. Vavilov (24)) is the preponderance of Victorian varieties in Table 2, but this is probably due to the more intensive search for them in this State. While there is no definite evidence to show that any or all of the varieties as they exist to-day were introduced accidentally from imported seeds or other material, there is also no evidence for an Australian origin of major variations.

Considering the varietal characters in two groups, (*a*) time of flowering (regarded as an expression of length of vegetative period, and capacity for branching), and (*b*) hairiness, anthocyanin, and leaf pattern, etc., only variations in respect to the first group are likely to be selected by the environment in a change of climate, such as from England to Southern Australia (Forster and Vasey (12)).

Combining with the Australian collection, the few varieties of direct European origin examined, one finds almost exactly the same range of maturity groups from both sources. Of the six European samples, those from Rouen and Berlin provided plants of both early and late maturity, while the others were pure lines in every respect; "Madrid" and "Liege" being early and similar to the early types from Rouen and Berlin, and "Cambrai" and "Rostock" being of the one late variety, distinct from the late Rouen and Berlin types.

No European variety exactly resembles any variety in the Australian collection, but the differences are only in "minor" and not in "major" characters, and if only the major characters are considered, counterparts can be found for each of the four European types in the Australian collection. The late variety "Rouen" is very close to "Kyneton" (Victoria); the early variety "Madrid" is much less hairy than the Victorian variety "Bacchus Marsh" of the same maturity group, and differs in

leaf markings; the variety "Rostock" is like the W.A. variety "Wenigup" in growth form and maturity, but differs in flower and leaf characters.

A survey of all available European descriptions and illustrations of the species (Table 3) shows few records of variations in minor characters and in node of first flower, and none of variations in leafiness. Only in 1934 did Ullmann (23) emphasize the practicability of selection of various maturity types, after a close study of Australian literature. He also described five European varieties (Appendix 2) varying in relative length of peduncle and petiole, in flower, calyx colour and in hairiness. The description of variety "longipes" fits our variety "Wenigup" and that of variety "brachycladum" is very similar to the variety "Second Northam." It is interesting to note in Table 3 that a form with a red banded calyx and striped stipules predominates in the English references, while a form with a green calyx and stipule is the one most described in French, German, Italian and Spanish records. Williams (27) found at Aberystwyth that the "Australian variety" (presumably Mt. Barker) had less anthocyanin flecking and colouring compared with the local native variety, but only a test under standard conditions, of samples from various English districts, could indicate the identity of the several red calyxed varieties with any in England, or with the variety "brachycladum" recorded in Italy (Appendix 2). Similarly, a much more extensive collection should be made in Europe and tested against the local varieties with green calyces, before their introduction here from abroad could be proved.

Mutations may have occurred in Australia in such characters as anthocyanin distribution, though the only direct evidence so far is the discovery of the white-seeded "bud" mutation in Dwalganup quoted above.

Evidence as to the origin of maturity types is difficult to obtain. The commonly accepted explanation of the development of district or local ecotypes by the operation of environment on a population of mixed genetic constitution, can be applied to any of the normally cross-pollinated pasture plants, as any sample will show marked plant to plant variation. This process cannot apply with equal force to a self-fertilized plant like *T. subterraneum* in any variety of which there is a remarkable lack of variation from plant to plant, in characters which might allow of environmental selection or modification.

There is no evidence whatever of any heritable response to altered environment in any of the varieties grown at Burnley over a period, in some cases, of twelve years. Seed has been harvested from each variety and resown the next year, but the varieties have shown an extreme stability of type, with no alteration of flowering date or other major characters, under an environment often widely different from that of the district where collected. A survey of the natural occurrence of maturity

types in Victoria (fig. 7) shows some correlation of maturity type with length of growing season, as would be expected from Trumble's emphasis on the minimum length of growing season necessary for effective seed production, and regeneration of the early and midseason varieties (21). Examination of fig. 7 shows a preponderance of the early varieties in unirrigated areas with about seven months growing season, and of the late varieties in the districts of South Gippsland, with nine to twelve months growing season. The data used in this map for the length of growing season usual in Victoria, is part of that published in 1939 by Trumble (22). The occurrence of two areas in which the winter temperature becomes too low for growth, should be noted, and also the areas south of Swan Hill which have the warmest winter in the State.

Late varieties, even if introduced, are unable to seed and persist in short season districts, but an early variety is able to persist if introduced into a district which would support a later strain, especially if not subject to competition from a later strain. As is shown in fig. 7, many early and mid-season varieties have been obtained from areas which could support a later strain and in some cases do so as well as the earlier one. Thus the natural occurrence of a certain maturity type in any given locality depends on (*a*) the chance of its arrival, (*b*) the local growing season as controlled by climate and topography, being at least the minimum necessary for regeneration, and (*c*) its ability to compete with other varieties or species present.

A late variety, on account of its capacity for greater seed production, will tend to dominate an earlier strain in a district of long growing season, but several maturity types often occur either separately or in mixture in the same locality, e.g. at Smeaton, "Bacchus Marsh," "Smeaton" and "Mount Barker"; at Drouin, "Bass," "Mt. Barker" and "Dwalganup"; at Ballan, "Bacchus Marsh," "Mt. Barker" and a late type; at Tumbarumba, "Mt. Barker" and "Tallarook;" while around Benalla, early, mid-season, late mid-season and late varieties occur. In a district of short climatic growing season, such local environments as river flats or irrigated fields allow the predominance of much later types, e.g. "Tallarook" near Seymour and a late volunteer type at Rochester, and in low areas near Yea, Tylden and Ballarat, where the mid-season "Mt. Barker" or earlier varieties otherwise predominate.

The whole of the varietal distribution data suggest a chance distribution, with environment preventing the persistence of late types in short-season districts, and more effective regeneration (heavier setting of seed) favouring the dominance of late varieties in long-season districts. In intermediate districts, several maturity types may co-exist, although in competition there is usually a tendency for a particular type to dominate in any one position.

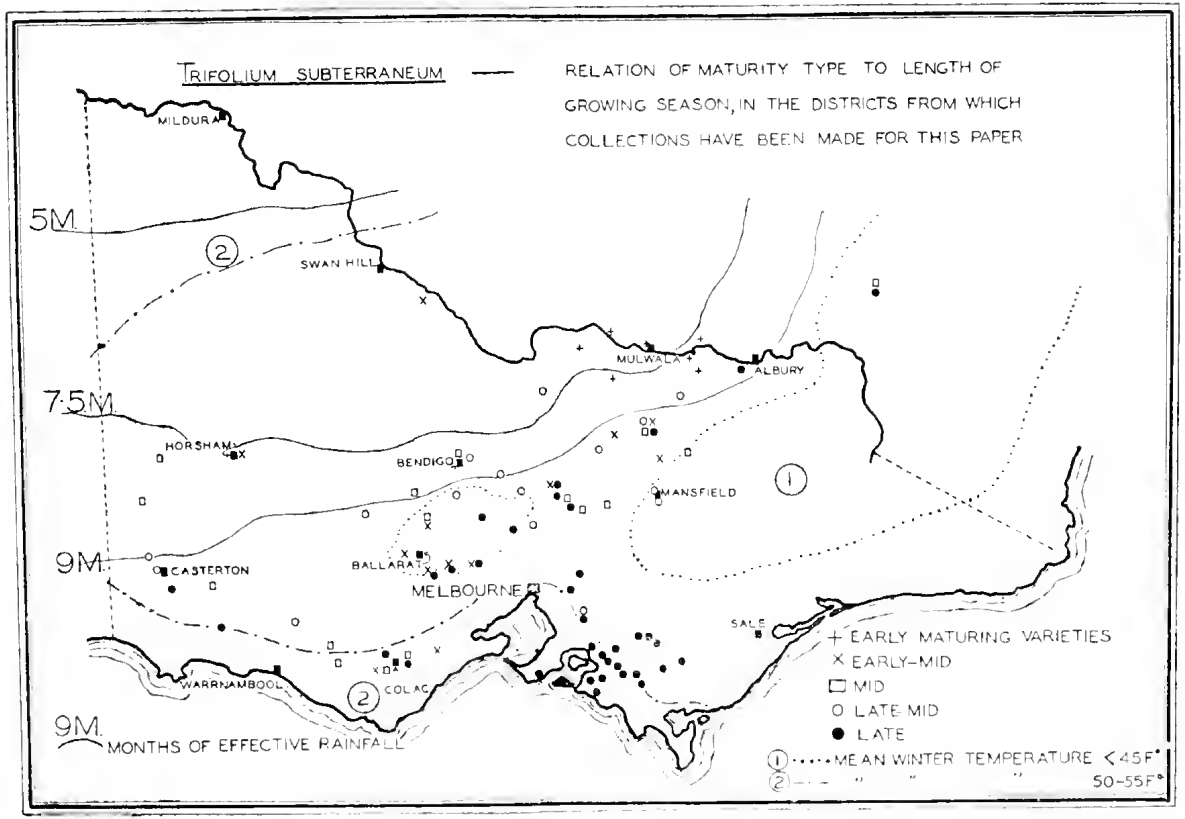

FIG. 7.—Map of Victoria, showing the relation of maturity type to the length of growing season, in districts from which collections have been made for this paper.

With no evidence of the occurrence of major variations in Australia, the evidence pointing to the accidental introduction into Australia of many of the varieties as they exist to-day, is summarized as follows:

1. The non-occurrence of any heritable alteration in major characters of the varieties when grown at Burnley over a period of twelve years, under changed environment.

2. The relatively short history of the species in Australia considered in relation to the extreme range of types isolated.

3. The absence of any closer correlation between the distribution of maturity types and the length of growing season of the district of their occurrence than can be explained as above (fig. 7 and discussion).

4. The existence in Europe of varieties differing only in minor, but not in major characters from certain Australian varieties.

This evidence appears to preclude the view that the varieties represent local ecotypes, developed in response to environment. The important question of how and when maturity variations occur may be answered only by close study under controlled conditions of the present maturity types, in order to find whether heritable variations in maturity can be induced.

Relation of Time of Sowing to Growth and Reproduction.

As an essential to the elucidation of the biology of *T. subterraneum* and to its best use as a pasture plant, the influence of time of sowing on its growth and reproduction has been investigated.

Sowings were made at weekly or fortnightly intervals at the Agricultural School and at Burnley Gardens, between May 1936 and April 1940. Three varieties were selected for study, as being typical of three major groups of Subterranean Clover, differing in the flowering date when sown in Autumn. The early variety "Dwalganup," flowering in early spring, and the late variety, "Tallarook," flowering in late spring, were studied from September 1938 onwards. The mid-season variety, "Mt. Barker," flowering in mid-spring, was used from May 1936; all sowings were made from stocks of certified seed.

In addition, in 1938 and 1939, simultaneous sowings of stock seeds from nine varieties, were made at several centres in Victoria and Tasmania, and in 1940, at several centres in New South Wales. In 1938, 1939 and 1940, the photoperiodic response was studied on certain plots from May to September. Each sowing consisted of at least fifty plants, sometimes many more. They were sown at 3-inch intervals with about a foot between the rows. In all cases, the seeds were sown with superphosphate and the plants watered when necessary, so that germination was never inhibited by lack of moisture in any of those tests.

Observations were made on the dates of (*a*) brairding—the appearance of cotyledons above ground; the period from sowing to brairding, being the *brairding period*; (*b*) flower initiation—the appearance of the first flower primordium at the tip of a basal runner; this was found by dissection under a binocular microscope (fig. 2), the period from brairding to flower initiation being the *rosette period*; (*c*) first flowering—this was taken as the date when the first flowers had appeared on half the number of plants in the row of 50; the *flower development period* is from initiation to first flowering; (*d*) seed formation—i.e. when seeds have developed in the burr sufficiently to be capable of germination; the *period of ripening* covers the time from the opening of the first flower to its successful seed formation. "*The vegetative period*" is that from sowing to first flowering.

The accuracy of the observations on the stages of development was high during most of the year, and variations in spacing had no effect on the time of flowering. As in wheat (12), the flowering dates recorded for plants of the summer sowings were variable, being somewhat affected by disease—Rust (*Uromyces trifolii*), a type of mosaic, and Red spider (*Tetranychus*), but much more so by variations in the physiological response of the varieties at that season.

A. Effect of Time of Sowing on Development.

As will be shown in the succeeding sections of the paper, the time of sowing had relatively little effect on the time taken for the periods of brairding, and ripening, compared with its effect on flowering, which was primarily an effect on flower initiation. The influence of time of sowing varied greatly with the variety.

Table 4.—Showing data for time required for germination of soft seeds of three varieties of *T. subterraneum*.

Incubator.			Field.	
Temperature °C.	Days to Production of Free, Green Cotyledons.		Soil Temperature at three inches Depth. Range of Fortnightly Means.	Time of Year.
30	2·9	..	..	..
25	3·1	6	20–28	Nov., Feb.
20	4	..	..	..
15	6	10	17–19	April
10	9	17	10	July
5	22	..	..	..

* In the Field Tests, the seed was planted at about 3 sths of an inch.

(1) *Brairding.*—In all varieties, the brairding period varied from six days (November to February) to ten days (early April), and to seventeen days (early July). It seems clear that this range could be reasonably attributed to soil temperature alone, as previous laboratory experiments had shown that in no variety did light affect the rate of germination of the seed. Table (4) compares the time taken, under various temperatures, for germination of the seed to the stage of free, green cotyledons, under laboratory and field conditions. The variation in the time taken for brairding in the field is of the same order as that taken under equivalent laboratory temperatures, but is relatively slower. This difference is more apparent than real, and is due to the impractibility of obtaining exactly comparable stages and conditions in the field and in a laboratory.

(2) *Flowering.*—During 1937 and 1938, observations were made on dates of seeding, brairding and flowering, and in 1939 and 1940 on the date of flower initiation also. Data for 1938 and 1939 have been arranged in fig. 8 to show the relation between time of sowing, and flowering, in the three varieties. Less than the number of observations are shown in these and other graphs for the sake of clarity, but no aberrant cases have been omitted.

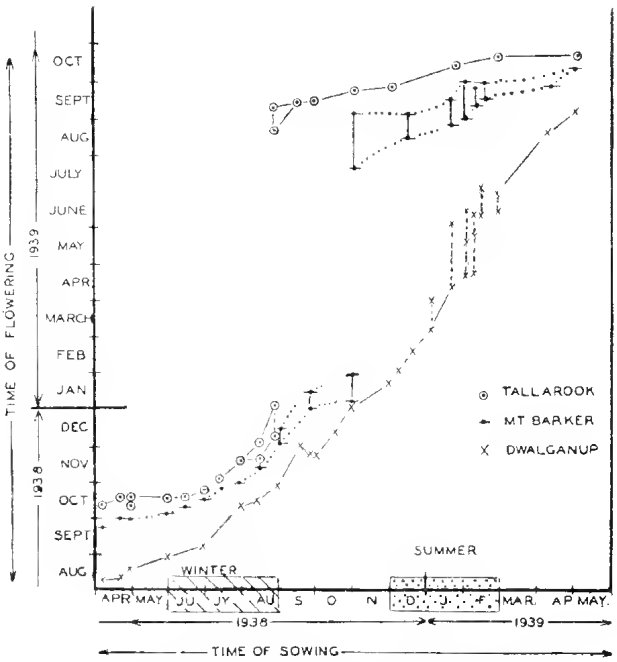

FIG. 8.—Graph showing the effect of time of sowing on time of flowering in three varieties in 1938 and 1939.

In the "Tallarook" variety, the plants sown at the usual time in early autumn (April), flowered in early October, after a vegetative period of six months. Sowing up to July reduced the vegetative period, but the date of flowering remained the same. Plants of the mid-August sowing, showed some variation in time and node of flowering (shown in the graph as a vertical line between the dates of first and last plants to flower). Some individuals were as much as four weeks later than others, instead of the normal difference of about one week. The late August sowings gave a few plants with runners which began flowering in December, but then died back, though the rest of the plant, and other plants of the row remained vegetative till the end of August 1939. From mid-August to late August is termed the "critical period" of sowing, because of the resultant variable flowering dates. The sowings from September onwards, produced plants that began flowering from the next September. Thus, there was a period of eight months vegetative growth between the flowering of the August sowings and that of the September ones. This behaviour recalls that of winter wheats sown in summer. (See fig. 2, Forster and Vasey (12).)

The results for "Mt. Barker," are comparable with those for "Tallarook," but certain differences are obvious from fig. 8. Attention is drawn to the fact that the critical period ends two months later, and, on the whole, the vegetative period is shorter for "Mt. Barker," whatever the time of sowing.

The behaviour of the "Dwalganup" variety showed marked differences from the other two. Plants sown in early April, flowered in August, a month before "Mt. Barker," and the date of flowering became progressively later with successive sowings. The critical period was from mid-January to the end of February, there was no period of complete cessation of flowering. During this period occasional plants entirely failed to flower and those which did develop, were confined to one or two runners. Sometimes there was a difference of two to three months between the flowering of runners on the same plant. The runners that flowered, varied in position from basal to younger ones, but once a runner started to flower, it proceeded normally.

It is noteworthy that the sowing of mid and late varieties during Summer, results in the plants flowering at about the same time as those sown in Autumn. This has also been noted from observations on self sown swards at Burnley, and at the Werribee Research Farm, where plants of mid and late season varieties, which had germinated in January, flowered in the same week as those sown in April (see also 6, 8, 10, 16).

In fig. 9, the vegetative periods for the three varieties are plotted against their respective times of sowing for 1937-40. It will be seen that the time of sowing has a great effect on the

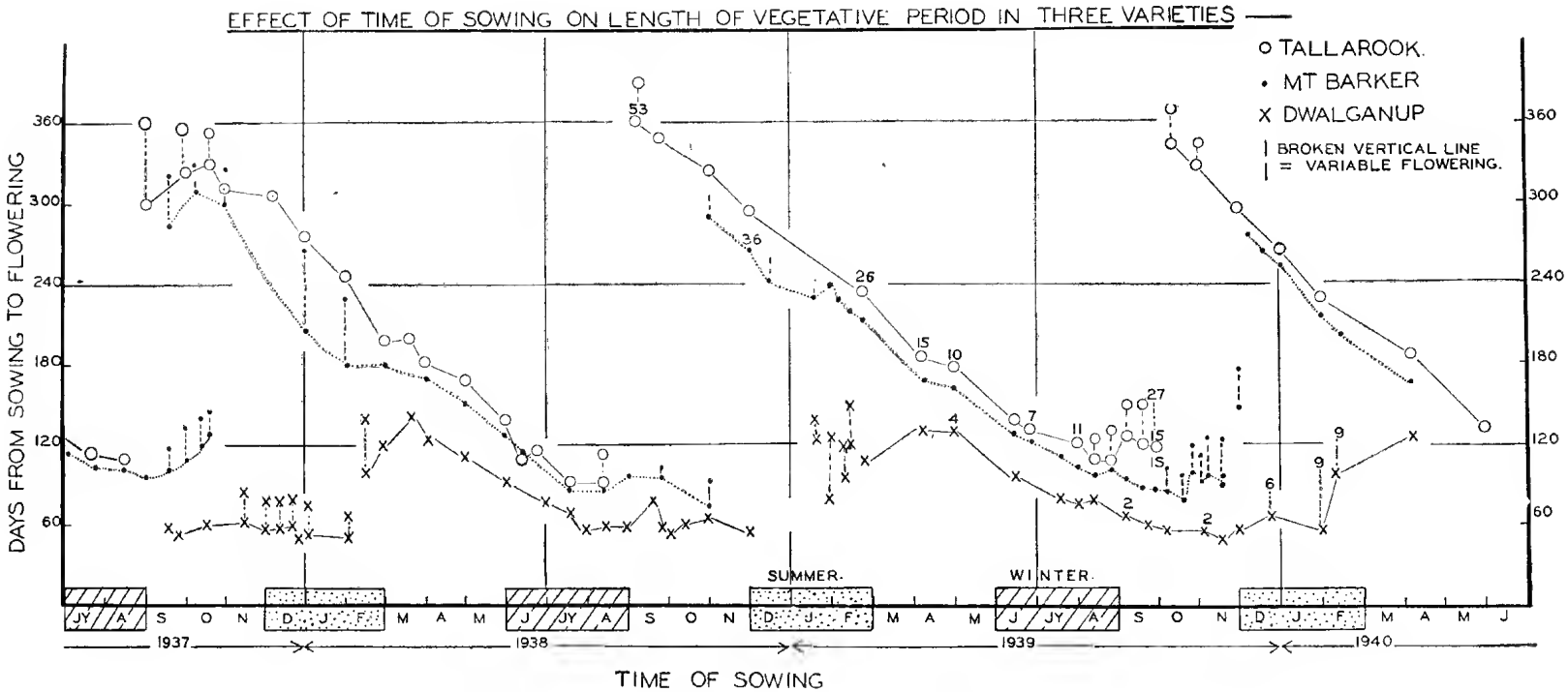

FIG. 9.—Graph showing the length of vegetative period in relation to time of sowing in three varieties, 1937 to 1940.

length of the vegetative period, which diminishes as sowings progress from Summer to the next Spring. The magnitude of this effect is summarized in Table 5.

TABLE 5.—EFFECT OF TIME OF SOWING ON LENGTH OF VEGETATIVE PERIOD, IN THREE VARIETIES OF EARLY, MID, AND LATE MATURITY. (Sowing from September, 1938, to August, 1939.)

Variety.	Longest Vegetative Period.		Normal Vegetative Period.		Shortest Vegetative Period.	
	Months.	Time of Sowing.	Months.	Time of Sowing.	Months.	Time of Sowing.
"Dwalganup" (early)	4	April–May	4	Early April	1¾	September to January
"Mt. Barker" (mid.)	9	Late November	5	Early April	2¾	Early October
"Tallarook" (late)	12	Early September	6	Early April	3¼	August

The problem is seen to be more complex, when the position of the flower on the basal runners of the plant, is examined. In fig. 9, for the 1939 observations, the node at which the first flower was produced, is indicated at several locations on the graphs. Immediately after the critical period in each variety, when the period of vegetative growth is at its longest, the number of the node at which the first flower is produced is highest. For the three varieties, the numbers of the nodes at which the first flowers form, from these sowings, are 50, 36 and 4 respectively. In plants originating from sowings immediately before the critical period, the corresponding figs. were 7, 6 and 2 respectively. Plants originating from the critical period of sowing, show an increasing variation between individual runners.

The season has some influence on the onset of the critical period, as is shown by a comparison of the years 1937 and 1938, with 1939. This will be discussed later.

(3) *Flower Initiation.*—It was of some interest to discover whether the variability in flowering was due to an effect on flower primordia formation, or on flower development. This was investigated for the three varieties in 1939 and 1940. The results for "Mt. Barker" are set out in fig. 10, which shows that the primary influence is on primordia formation. Fig. 11 shows, for all three varieties, the length of the interval between primordia formation and flowering, and also in many cases, the number of the node at which the first flower appeared. It seems reasonable to assume that the changes in the length of the flower development period from month to month, are explicable as an effect of temperature on the rate of growth of the primordia.

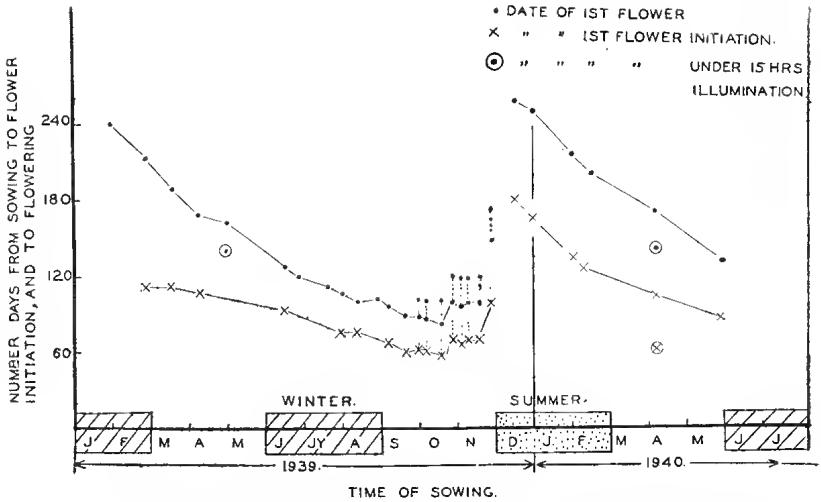

FIG. 10.—Graph showing the length of time from sowing to flower initiation, and to flowering, and hence the relation between flower initiation and flowering in "Mt. Barker" variety.

Such a temperature effect was observed in the rate of node formation along a runner; the rate increased from mid-winter to the summer months, being fourteen days per node in winter, and only four days in the summer.

Fig. 11 also indicates the time at which flower initiation begins. For "Tallarook," the earliest flower initiation began in mid-August, and continued normally till the beginning of November;

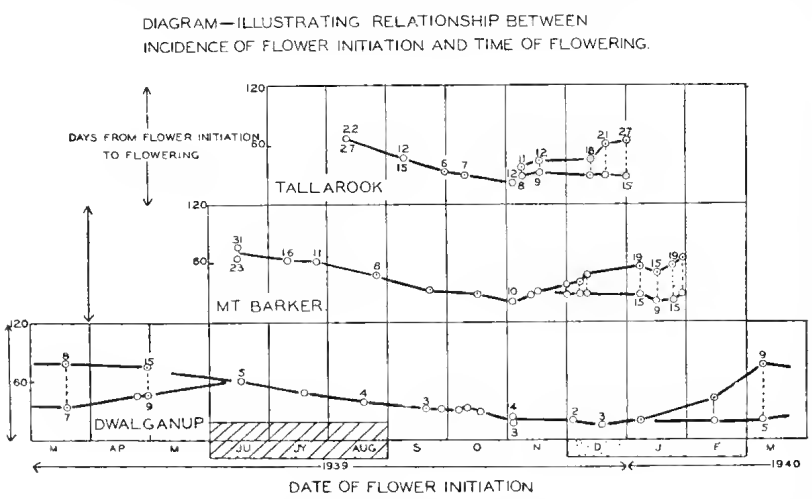

FIG. 11.—Graph showing the relation of the length of the period from flower initiation to flowering, to the date of flower initiation; and the incidence during the year of the beginning, variability and end of initiation for the three varieties

for "Mt. Barker" the corresponding period was from mid-June to the beginning of January; and for "Dwalganup," flower initiation occurred all through the year, but was somewhat unstable between February and March in 1940, and March and April in 1939.

(4) *Seed-formation.*—The time taken for seed-formation, varied from one month after flowering in October, to about three months, after flowering in May. Exposure to a fifteen hour length of day in the winter did not hasten the period, and it is apparently dependent on the temperature only. The developing embryo may be killed a few days after flowering, through desiccation in summer, or by low temperatures in winter.

A wide variation in size of seeds often occurs along a runner, due to the time interval between the flowering of the first and the last axillary inflorescences along a runner, and to the decreasingly favorable conditions for seed development during this period.

Comparing the April sown varieties at Burnley, the minimum time taken for seed formation varies from about six weeks for the early varieties, to five weeks for the mid-season ones and to four weeks for the late ones. For the main maturity types, the total period necessary from sowing to seed formation, for minimum regeneration is thus assessable, and can be compared with the average length of growing season of any district.

B. Discussion.

It is obvious from the preceding sections, that the time of sowing has a marked effect upon the length of the vegetative period, and on the time of flower initiation and flowering. (The less marked effects on brairding and flowering will not be discussed here.) There is ample evidence in other work, that these effects might be due to the differences in length of day, to which the plants from the various sowings were subjected during their development. An experiment on Subterranean clover itself, has shown that a continuous, long period of daily illumination may cause earlier flowering. Certain plants were treated from May to September, with an extra period of artificial illumination the intensity of which was 30-foot candles at plant level. The total period of continuous illumination was fifteen hours in each twenty-four. This treatment, applied to plants of each variety, sown in April and in February, caused the flowers to appear three or more weeks earlier than on the controls. As might be expected, the plants whose vegetative period had been reduced by the "long day," produced flowers on nodes nearer the axis, i.e., these plants resembled morphologically, field plants produced by sowings just before the critical period. Thus while the node number of the first flower in "Dwalganup," was reduced

from four to two, in those of "Mt. Barker" it was reduced from ten to six, and in those of "Tallarook," from fifteen to seven (Plate XVII., fig. 1, and cf. fig. 9). It is concluded that the later the variety, the greater the response to a summer length of day, in respect to the "node number."

Examination of fig. 12 will show however, that the interpretation of the field data is by no means as simple as is suggested by these experiments on the effect of increased daily illumination. The variations in the length of day experienced throughout the year in Melbourne, are plotted as a heavy line on the upper section of fig. 12; the mean minimum weekly temperatures from September, 1938, to December, 1940, are shown as a fine line. In the lower section, length of vegetative period, flower initiation, and flowering during this period, are arranged horizontally, in the order of sowing. The data is for "Tallarook."

There is some indication that the length of day may affect the date of flower initiation in the field. Thus at *E*, the time from sowing to initiation is five months, and the length of day ranges from $9\frac{1}{2}$ to 11 hours. As the length of day increases, the time from sowing to initiation decreases, partly due to an increased rate of growth, but also, to initiation at a lower "node-number"; e.g. at *A*, where the node-number is only seven, compared with that of fifteen resulting from the sowing at *E*.

Comparing the group of sowings from *A* to *B* however, it can be seen that they all have about the same vegetative period. But the plants sown at *A*, had an average length of day of $10\frac{1}{2}$ hours, and flower initiation began before it reached $12\frac{1}{2}$ hours per day, whereas those sown at *B* germinated when the length of day was $12\frac{1}{2}$ hours, and began flower initiation when it reached 15 hours per day. Intermediate sowings gave intermediate results. Here, obviously, the average length of day during the growing period is not correlated with the time of initiation or the length of vegetative period. Comparing those plants sown at *C*, and at *D*, it is clear that they are both subjected to approximately the same length of day (rising from 11 to $14\frac{1}{2}$ hours per day), during the first two months of their vegetative life. Those at *C* formed flower primordia in early November 1938 (two months after sowing), but those at *D* failed to form primordia till August 1939 although experiencing a length of day of 14 to nearly 15 hours from November to February. Thus it is clear that some factor or factors, in addition to day length, must affect flower formation, at any rate during Spring.

The incidence of high temperatures was then analysed, as it had been shown experimentally by Hamner and Bonner (14), and Roberts and Struckmeyer (20), that night temperatures above a certain level prevented flowering in a number of plants, including some legumes, despite a favorable length of day. The

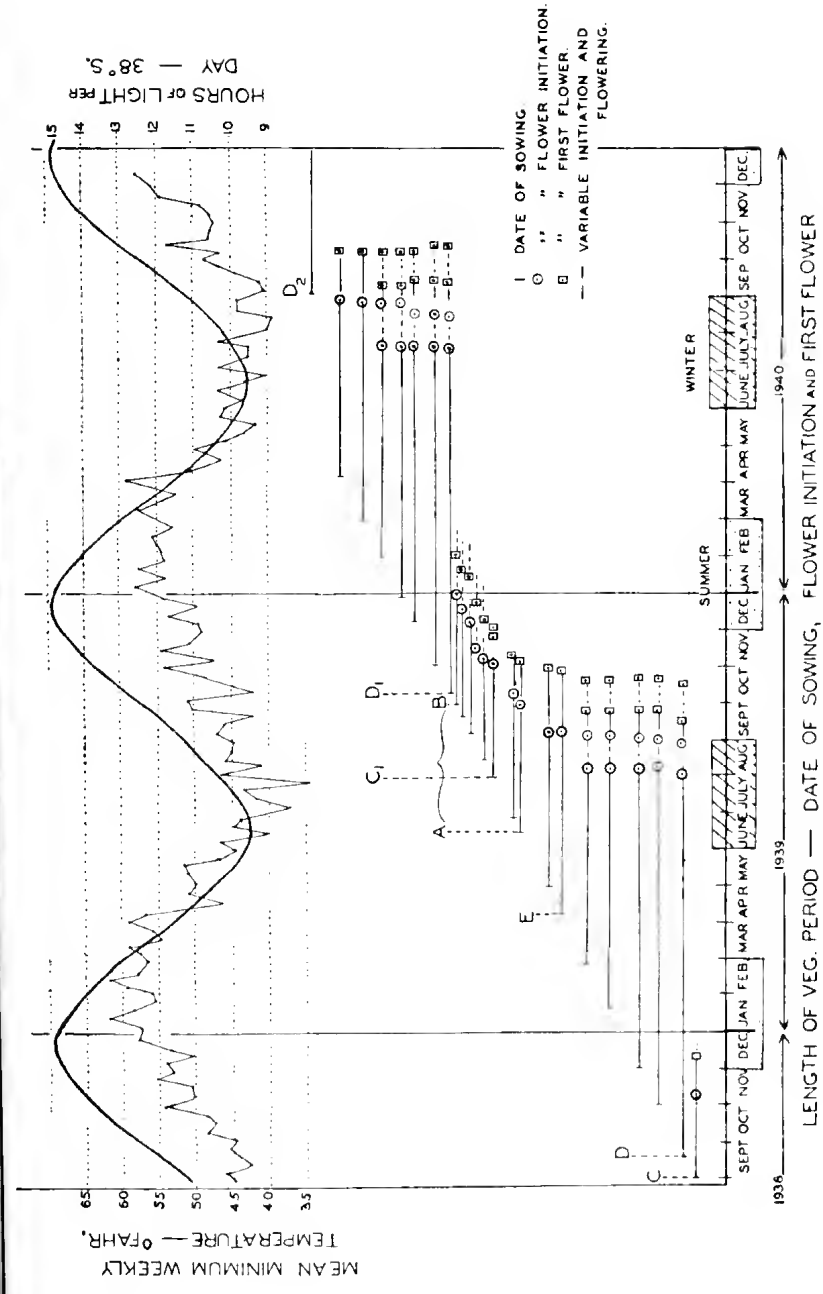

FIG. 12.—Graph, showing the relation between length of day and mean minimum temperature, and the behaviour of plants sown in the years 1938 to 1940.

figures for the mean minimum weekly air temperatures are therefore given also in fig. 12. It is evident that the temperature rises and falls with the length of day, but the maxima and minima occur about a month later in each case.

Referring again to the sowings at *C* and *D*; the plants sown at *C* developed under a night temperature increasing from 45°F. to 50°F. But the temperature only rose above 50°F. the week before flower initiation, and it fell to 50°F. again, for the next two weeks, before rising above this level continuously for the next four months. Those sown at *D*, however, experienced a rise in temperature to above 50°F. several weeks before flower initiation would have occurred, judging from the time taken in plants of the previous sowing. The remarkable difference in the flowering dates for *C* and *D* is shown in fig. 12.

Considering the behaviour of plants sown in the spring of 1939, at D_1 temperatures above 50°F. became continuous two months after sowing, and again flower initiation did not occur till the next July.

Plants sown from C_1 to *B*, correspond to those of the previous year, sown at *C*. That is, they are not subjected to continuous periods above 50°F., and they have a short vegetative period. These plants showed an increasing variability of flower initiation, and it can be seen that flower initiation in this group occurs over the perod when the temperatures were fluctuating about 50°F.

Considering the results in both years, the first sowing resulting in a prolonged vegetative period, occurred earlier in the spring of 1938, than in that of 1939; it is clear that the temperature level rose continuously above 50°F., earlier in 1938.

It is therefore concluded provisionally, that the failure to flower, in plants sown just after the critical period, is possibly due to the incidence of high temperatures. If the weekly minimum temperature rarely falls below 50°F. at a time when flower primordia could normally be formed, then it seems that even under the most favorable length of day, flower initiation is inhibited. If this explanation is correct, then it follows (see fig. 12) that this temperature effect is not rapidly reversible, for even when the temperature has fallen well below 50°F., the plants sown at D_1 still remain vegetative for four months. They finally form primordia, when the temperature is between 40° and 45°F., and the length of day only 10½ hours.

There is, however, another possible explanation of the prolonged vegetative period in the plants of type *D*. It may be that flowering is delayed not because of a high temperature but because of the lack of a suitably low temperature. In the normal vernalization theory, as applied to wheats, the low temperature "thermo-stage" must precede the "photostage." Applying this to clover we note that plants sown between *A* and *B* pass the

early stages of their vegetative life when the temperature is between 35° and 45°F. and they flower after a relatively brief vegetative period. Plants sown at D_1, however, experience a high temperature (as well as a long day) during their early vegetative life and do not form primordia until late winter, when the temperature has again fallen to between 40° and 45 F. The evidence therefore allows the suggestion that the plant must receive at some time in its vegetative period, and not necessarily before it receives the long day, a period of low temperature before flower initiation can take place.

If the view is adopted that flowering is inhibited by high temperatures, then the data indicate that the inhibition temperature is near 50°F. for "Tallarook," 53 F. for "Mt. Barker" and about 58°F. for "Dwalganup." A temperature level sufficient to prevent flower initiation in "Dwalganup" is not reached in Melbourne, but the critical period of flowering in this variety is associated with fluctuations about the 58°F. level. If we adopt however the vernalization hypothesis (i.e. necessity for a low thermo-stage) then it may be that "Dwalganup" differs from the other two varieties in not requiring temperatures below 45 C. during its thermo stage. Only further experiments can distinguish between the two hypotheses, and these are now being undertaken.

C. Effect of Latitude and Season on Time of Flowering in Autumn Sown Plants.

It has been shown that with autumn sown plants, the later the variety the greater the response to a long daily period of illumination; and that the earliest flower initiation possible in "Tallarook" varied between the end of July to the middle of August, with a length of day increasing from 10 to 11 hours. Conversely, the earliest variety could initiate flower primordia all through the year, though it could be hastened slightly by lengthened daily illumination. It might thus be reasoned that the late variety grown in more northerly districts in southern Australia, would show earlier flowering due to the earlier incidence of a length of day of more than 10 hours, and conversely with districts south of Melbourne. To investigate this effect of latitude, sowings of nine varieties of early to late maturity were made at places ranging from Launceston to Sydney.

Typical results of such sowings are shown in Table 6, but only those for the varieties "Dwalganup," "Mt. Barker" and "Tallarook" are included as they are representative of the early, mid and late maturity groups.

Considering the varieties sown in early April of 1938, those at Walpeup flowered about a week earlier than those at Burnley, but of those at Launceston, the late variety flowered at the same

TABLE 6.—EFFECT OF DISTRICT OF SOWING ON THE TIME OF FLOWERING OF VARIETIES, WHEN SOWN AT THE SAME TIME.

Places Where Tested.	Latitude.	1938.			1939.			1940.			Incidence 11-hour Day in Spring.	10-hour Day.
		Dwalganup.	Mt. Barker.	Tallarook.	Dwalganup.	Mt. Barker.	Tallarook.	Dwalganup.	Mt. Barker.	Tallarook.		
Sown April 8.												
Sydney	33° ·5	..	..	..	..	..	..	July 25	Sept. 4	Sept. 25	Aug. 19	July 6
Canberra	35° ·2	..	..	..	..	..	..	Aug. 28	Oct. 5	Oct. 23	„ 20	„ 12
Walpeup	35° ·1	Aug. 10	Sept. 19	Oct. 4	Aug. 12	Sept. 25	Oct. 5	„ 17	Sept. 21	„ 7	..	..
Rutherglen	36°	„ 12	„ 25	„ 6	„ 12	„ 27	„ 9	..	..	..	..	..
Burnley	38°	„ 15	„ 27	„ 12	„ 17	„ 27	„ 24	„ 14	„ 22	„ 5	„ 24	„ 7
Launceston	41° ·2	Sept. 5	Oct. 3	„ 11	Sept. 7	Oct. 10	„ 24	..	..	..	„ 28	Aug. 1
Sown April 28.												
Swan Hill	35° ·2	Aug. 20	Sept. 21	Sept. 25	..	..	Sown April 29 Kerang (35° ·4)	Aug. 25	Sept. 25	Oct. 12	..	..
Cohuna	35° ·4	„ 16	„ 21	Oct. 3	..	..	..	..	..	..	..	..
Burnley	38°	Sept. 1	Oct. 1	„ 13	..	..	..	..	..	..	..	..
Launceston	41° ·2	„ 23	„ 7	„ 14	..	..	..	..	..	..	..	..

time as that at Burnley; the mid-season one was a week later, and the early one was three weeks later. At Walpeup in 1939, only "Tallarook" flowered much earlier than at Burnley, while at Launceston the late variety again flowered at the same time as at Burnley. Taking a length of day of 11 hours as probably necessary for flower initiation in "Tallarook" plants sown in autumn, it can be seen in Table 6 that this is reached by Aug. 24, at Melbourne, and only four days earlier and later respectively, at Walpeup and Launceston. The difference is comparatively small, and also, no clear gradient is obvious in the commencement of flowering of the late variety in the three places. The difference between the results of the earlier varieties at Melbourne and Launceston is much greater than between Melbourne and Walpeup, and the later flowering of "Tallarook" in 1939, compared with 1938 at both Burnley and Launceston, is also noteworthy, as occurring when a cooler spring period was experienced over these districts. In addition, the node at which the first flower was produced along the basal runners, did not vary in number, as would have occurred with a sufficiently wide difference in incidence of the favorable length of day. It may be reasonably concluded that differences in temperature levels experienced in the various districts, affect the rate of vegetative growth of the varieties, and so their times of flowering. This is further supported by the observation that the plants reached certain stages in their growth (such as that of four leaves per plant) earlier, when growing in the northern districts, and later, when growing at Launceston; and that flower initiation in "Tallarook" was some days earlier at Walpeup and Kerang, than with plants sown at the same time in Melbourne.

In 1940, results were also obtained from Sydney and Canberra. Comparing them with those from Walpeup and Burnley, it is interesting to note that the first three places have approximately the same incidence of an 11-hour day, but the flowering of all three varieties is much earlier at Sydney, and much later at Canberra than at Walpeup. Reference to such a measure of temperature levels as the average monthly minimum temperature, shows that the figures for Sydney, from June to September are from 7° to 4°F. above those for Melbourne, while for Canberra, they are from 9° to 7°F. less than those for Melbourne.

Within the range in length of daily illumination occurring from Launceston to Sydney, the effect of decreased latitude for the plant appears to be due to the associated trend in climate from cool to warmer, and where two districts of the same latitude differ sufficiently in the temperature levels of the growing season, the varieties will show the differences, in their commencement of flowering.

Observations on Production According to Variety and Environment.

Most of the following notes on the comparative productive capacity of varieties have been taken on the spaced plants in the plots at Burnley Gardens. Growth under such conditions gives any plant the chance to show its full productive capacity, and also allows comparative study of varietal development; whereas under sward conditions, lateral development, functioning leaves, number of runners, and hence differences between varieties, are much reduced. These observations are thus preliminary to the essential investigation of varietal production in relation to sward conditions and to length of growing season. They are, however, free from the effects of the factors of competition, which may act differentially between varieties.

From two to four typically developed plants were used for each measurement. The quantitative data obtained from these observations were scarcely likely to be statistically acceptable, as the basis of detailed hypotheses, but they were sufficient to give information on varietal differences of a major type.

Time of varietal differentiation in leaf, dryweight, and burr production.

To ensure that the varieties could be compared in their development, observations were taken on those plots in which they had all germinated in the second week in April.

It has been pointed out previously, that many of the varieties differ greatly from each other in leaf and dryweight production at flowering time, owing to variations in runner development. A periodic count of leaves per plant in 1940, the results of which are set out in Table 7, showed that this variation commenced in late June, after which date, initiation of new runners was slower in the early variety, "Dwalganup," and the late one,

Table 7.—Comparative leaf development in varieties at various dates—1940.

Maturity.	Variety.	Number of Leaves per Plant at—					
		July 1.	Aug. 1.	Aug. 22.	Sept. 17.	Oct. 15.	Nov. 15.
V.E. ..	Dwalganup ..	15–20	20–30	15–25	40	120	120
V.E. ..	Mulwala	20	30–40	25–30	100	200	250
E. ..	Reigert's White ..	20	20–30	30–40	60	..	230
E. ..	Springhurst ..	25	30	25–30	40	200	220
E.M. ..	Bacchus Marsh ..	25	30	35–40	100	450	550
M. ..	Mount Barker ..	25	30	30	60	430	450
L.M. ..	Nangeela ..	25	30	30–40	90	650	650
L.M. ..	Mansfield ..	25	40–60	40–60	130	750	750
L.M. ..	Burnerang ..	25	40–60	40–60	140	400	670
L. ..	Merino	20	30–40	40	..	500	750
L. ..	Macarthur ..	20	40–50	40–50	120	500	820
L. ..	Tallarook ..	15	40–50	40–50	70	550	850
L. ..	Bass	15	30	30	80	500	750
L. ..	Wenigup ..	10	15–20	20	40	..	400

"Wenigup," than in the other varieties; hence the former varieties showed fewer leaves. By August, the late mid-season varieties, "Mansfield" and "Burnerang," had developed twice, and the late ones, "Macarthur" and "Tallarook," nearly twice the number of leaves formed by some of the early varieties: by mid-September, "Mansfield," "Burnerang" and "Macarthur" had more than three times the leaves of "Wenigup" and "Dwalganup," owing to their larger numbers of runners and laterals; but in this particular year, relative figures were not quite normal because of the unusually dry period. By November, most of the later varieties had six or more times the number of leaves of the now senescent earliest ones. Consequently, the ratio of leaf to dryweight was much higher in the leafy later varieties.

It is clear from Table 7, that the rate of leaf production per plant was small up to September, and that the general great increase in growth responsible for the well known "spring flush" in the field, began in mid-September, under Melbourne conditions. Such an increase had been noted about the same time in 1938, and some weeks later, in 1939. Reference to fig. 13, giving the figures for mean soil temperature at 6 inches,

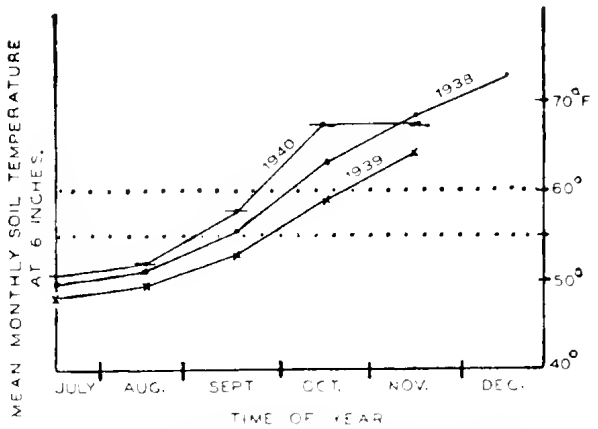

FIG. 13.—Graph, showing the incidence of the rise in mean soil temperature at 6 inches, in the spring of 1938, 1939 and 1940, at Melbourne.

between July and December, showed that in the three years, the conspicuous increase of growth occurred when the temperature rose from below 55°F. to above 60°F. Thus the incidence of the spring flush may be expected to vary according to the district, because of its particular characteristics of spring temperature levels. Early spring feed thus depends on the possibility of getting a useful increase in leaf production earlier than usual—earlier in September for Melbourne. A closer study of varietal growth during this time should show if any variety has outstanding value in this direction.

The dryweight per plant increases with plant development and with the "maturity type" of variety, but varieties within each "maturity type" group differ somewhat in this respect. Table 8 shows that in mid-September, there is little difference in dryweight between the varieties, but by early November, the range between them is wide, and of the two with very early maturity, Mulwala is distinctly superior.

TABLE 8.—INCREASE IN DRY WEIGHT AND BURRS PER PLANT WITH MATURITY, 1937.

Maturity.	Variety.	Date—					
		September 15.		November 1.		December 16.	
		Dry Weight. (*a*)	Burrs. (*b*)	Dry Weight. (*a*)	Burrs. (*b*)	Dry. Weight. (*a*)	Burrs. (*b*)
		Grams.	No.	Grams.	No.	Grams.	No.
V.E. ..	Dwalganup ..	5	10	8	70	7·5	60
V.E. ..	Mulwala	7	4	29	40	35	100
E. ..	Daliak	3	5	9	130	..	..
E. ..	Springhurst ..	4·6	0	25	60	27	100
E.M. ..	Bacchus Marsh ..	4·2	0	33	85	35	340
M. ..	Mount Barker ..	5·3	0	24	16	35	450
L.M. ..	Nangeela	6	0	48	6	..	..
L.M. ..	Burnerang ..	6	0	27	4	50	370
L. ..	Tallarook	5·2	0	26	8	60	550
L. ..	Bass	5·6	0	..	0	45	220
L. ..	Wenigup	6	0	22	2	70	50

The time at which seed production begins, varies according to the time of maturity of the variety. Table 8 shows that the early varieties had developed several mature seeds by late September, and had finished seed production by November; the mid-season varieties had begun in mid-October and finished in late November, while the corresponding periods for the late ones were in early November and late December. The early cessation of seed formation in the early varieties, in addition to their relatively small capacity for flower production, causes a lower amount of seed formation than in the later maturing varieties. The time taken from germination to the formation of the first burr, gives an indication of the minimum length of growing season necessary for the minimum regeneration of the variety.

EFFECT OF GROWING SEASON ON VARIETAL PRODUCTION.

Investigations by Donald and Smith (10) at the Waite Institute 1935-36 showed that leaf and dryweight production was closely correlated with lateness of maturity, as measured by the time of flowering. The lengths of the growing seasons in the two years of their experiments were 5.5 and 5.0 months respectively owing to late sowing, although the full growing season during these particular years was 8.7 and 7.6 months. They also demonstrated

the importance for seed-setting and maturation, of the daily evaporation from the eighth to the twenty-eighth day after commencement of flowering, and the superiority of "Tallarook" in setting seed under severe conditions. Their investigations were repeated under Melbourne conditions, in order to find the relevance of these results locally. In 1937 it was observed that the date of the appearance of the greatest number of flowers per plant—"maximum flowering"—occurred from four to three weeks later than the opening of the first inflorescence, and this is probably connected with the significance of the evaporation level during the first month after flowering.

Eleven varieties were selected to represent a full range of maturity groups, and several other varieties gave additional data. Observations were taken at the end of the growing seasons of 1937-8-9 on seed-setting, and on the dryweight per plant, excluding roots and burrs (see Table 9).

The plants were sown in the first week of April in the three years during which observations were taken. Seven of the varieties were among those which had been tested at Adelaide. The same order of result was obtained except that the increased number of late varieties studied, showed that the seed-setting of Tallarook was not particularly superior, even under drought conditions.

In 1937, the growing season was somewhat dry (7.6 + months) for Melbourne, and the length of growing season ($^{P}/_{E} > \frac{1}{3}$) beginning from April, was 7.3 months. The dryweight per plant showed an increase in relation to maturity (col. *a*), in the few varieties tested. The yield of burrs per plant (col. *c*), also increased with length of the vegetation period of the type, but within the early group, the variety "Mulwala" developed more burrs than another early one, "Dwalganup", and among the late varieties, "Tallarook" gave a higher yield than "Wenigup." However, considering the yield of seeds per burr (col. *d*) it is seen that there is comparatively little variation between the varieties, and that if "Wenigup" is excepted as a variety with abnormal inflorescence formation, there is no indication of a lower yield in the later varieties. This lack of agreement with the Adelaide results was thought to be due to the lower evaporation prevailing in late spring. In this particular season, Melbourne weather conditions (6.3 + months) suited the late varieties.

In 1938, a drought year, the growing season was only 5.3 months ($^{P}/_{E} > \frac{1}{3}$) from April, and the spring evaporation was very close to that experienced in Adelaide in 1936. The dryweight per plant again showed an increase with lateness, but as a result of the dry conditions, the weight per variety was reduced, especially in the later ones, compared with the yield in 1937. The yield of burrs (*c*) was variable, but "Bacchus Marsh" and

TABLE 9.—A COMPARISON OF SEED-SETTING AND DRY WEIGHT PRODUCTION PER PLANT IN THE GROWING SEASONS OF 1937-39, IN VARIETIES RANGING IN MATURITY FROM EARLY TO LATE.

Maturity.	Variety.	1937.			1938.						1939.					
		Dry Weight per Plant (exc. burrs or roots).	Burrs per Plant.	Seeds per Burr.		Inflorescences per Plant.			Seeds per Inflorescence.	Ratio of Burrs to Inflorescenses						
		a.	*c.*	*d.*	*a.*	*b.*	*c.*	*d.*	*e.*	*f.*	*a.*	*b.*	*c.*	*d.*	*e.*	*f.*
V.E.	Dwalganup	7·5	60	..	7	165	25	2·6	0·4	1 : 6·5	10	170	50	2·8	0·9	1 : 3·2
V.E.	Mulwala	15	100	2·8	10	285	80	2·7	0·7	1 : 4	25	460	240	2·6	1·4	1 : 1·9
E.	Springhurst	21	100	..	17	295	50	2·6	0·4	1 : 6	25	300	90	3·2	0·9	1 : 3·3
E.M.	Bacchus Marsh ..	32	340	2·8	22	595	125	3·3	0·7	1 : 4·8	55	900	450	3·0	1·5	1 : 2
M.	Mt. Barker	..	420	2·6	10	340	45	2·4	0·3	1 : 8	30	1330	590	2·6	1·2	1 : 2·2
L.M.	Mansfield	..	..	..	30	930	165	2·3	0·4	1 : 6	..	..	..	..	..	..
L.M.	Nangeela	..	..	3·2	34	570	30	2·4	0·1	1 : 21	50	1130	670	3·0	2·3	1 : 1·7
L.M.	Burnerang	50	380	2·7	19	195	80	2·0	0·3	1 : 2·5	30	1250	860	2·8	1·2	1 : 1·5
L.	Macarthur	..	..	2·7	21	540	65	2·6	0·3	1 : 8	..	1580	1500	2·9	2·8	1 : 1·05
L.	Merino	..	..	..	29	675	60	..	..	1 : 8	..	900	..	2·5	..	..
L.	Tallarook	60	550	3·2	27	635	95	2·6	0·37	1 : 7	50	1350	1030	2·8	2·0	1 : 1·3
L.	Wenigup	70	220	2·1	25	730	41	2·2	0·1	1 : 1·8	..	550	150	3·3	0·9	1 : 3·7
L.	Bass	..	..	2·8	..	..	..	..	..	..	..	2060	1010	4·0	2·0	1 : 2

"Mansfield" gave the best yields. Compared with that of the previous year, there was a definite indication of the yield of later varieties being more reduced. However, the yield of seeds per burr (*d*) showed only a slight decrease in most cases. Further data obtained (cols. *d*, *e*, *f*), gave more information. A count of the approximate number of inflorescences (col. *d*), produced per plant, showed a general increase with lateness of maturity, but there were large differences between varieties of the one group, e.g. "Burnerang," "Nangeela" and "Mansfield." The Melbourne figures for seeds per inflorescence (which in Adelaide were associated with evaporation), showed that several varieties were poor, compared with the rest, e.g. "Nangeela," in the late midseason group, and "Wenigup," in the late group; but there was again no definite trend of low yield with lateness. The varieties "Mulwala," "Bacchus Marsh," "Mansfield" and "Tallarook," appeared somewhat superior to the rest under drought conditions. The figures for the ratio of number of burrs to number of inflorescences (col. *f*) emphasizes the inferior burr-formation of "Nangeela" and "Wenigup."

In this particular season the climatic conditions for Melbourne being similar to the seasons investigated by the Adelaide workers, gave similar results; but the variety "Tallarook" is now seen to have its equals in other late varieties, "Merino" and "Macarthur."

In 1939, a year of abnormally high rainfall, the growing season from April was 8.3 months. All the columns show an increase in yield compared with 1938, especially in cols. *e* and *f*. The increase is particularly noticeable in the varieties that gave the poorest yields under drought conditions.

The effect of the 1938 and 1939 growing seasons was also shown by the yields of burrs from sample quadrats taken on an established sward of the "Mt. Barker" variety. In 1938, the yield from a decimetre square quadrat was 120 burrs, and in 1939, 250 burrs with more than twice the total number of seeds.

From the data on varietal flowering and seed production at Melbourne, a tentative table (Table 10) has been drawn up, to indicate the length of growing season necessary for minimum and aggressive regeneration of some of the more important varieties. The figures stated by Trumble for three varieties, are included, and are necessarily somewhat lower because of the higher temperature level available in South Australia for growth in the winter.

It is noteworthy that in 1938, with a growing season of only 5.3 months, ending just before September, both the mid and the late varieties set a fair amount of seed, under spaced plot conditions. Even under sward conditions "Mt. Barker" set as much seed as in the variety plot. It seems likely that, at least in Melbourne, plants can continue growth sufficiently to set seed,

for at least two months after the ratio of precipitation to evaporation has fallen below one-third. This should be tested further in order to define more accurately the effective length of growing season for Southern Victoria.

TABLE 10.—MONTHS OF EFFECTIVE RAINFALL, FOR PERSISTENCE OF VARIETIES IN SOUTHERN VICTORIA, WHEN GERMINATING SECOND WEEK IN APRIL.

Maturity.	Variety.	Months to First Flower.	Months to Minimum Seed-setting.	Months to Maximum Seed-setting.	Months for Persistence in South Australia (4, 15).
V.E. ..	Dwalganup ..	4·5	6·0	7·5	6
V.E. ..	Mulwala	4·5	6·0	7·5	..
E. ..	Springhurst ..	4·8	6·0	7·5	..
E.M. ..	Bacchus Marsh ..	5·1	6·5	7·8	..
M. ..	Mt. Barker ..	5·5	7·0	8·0	7·5
L.M. ..	Mansfield	5·7	7·0	8·5	..
L. ..	Macarthur ..	5·9	7·0	8·5	..
L. ..	Tallarook	6·2	7·0	8·5 +	8·25
L. ..	Bass	6·5	7·5	8·5 +	..

Summary.

The type variety of the species in Australia—" Mt. Barker," is fully described.

Genotypical variation is found to occur in the same characters as occur in such other leguminous species as *Vicia sativa,* and *Pisum sativum.* Fifty varieties are described by means of a table of observed heritable characters.

The characters are grouped as major—those influencing the growth structure, and so the plant's capacity to produce leaves, flowers and seed, and minor—those causing variations in anthocyanin development in leaf, calyx, corolla, stipule, stem, seed and hypocotyl, and hairiness of plant surfaces (leaf, stem, and calyx).

Five major characters make up the " basal runner organization," which is typical for each variety. The characters of number of runners per plant, lateral development, internode length, and seed-production per plant, are all strongly influenced by the time of flowering peculiar to each variety. But, in addition to this influence of time of flowering on productive capacity, there is variation in these major characters within each maturity group, so that choice is possible of the most productive variety for a given length of growing season.

There is indirect evidence that the range of maturity types has not originated under various local conditions within the last 50 years, though there has been some control of the predominance of the early and late maturity types in Victoria, through length of growing season. There is some evidence that minor mutations, changing the anthocyanin development characteristic of a variety, have occurred in Australia.

The time of sowing through the year, influences the length of the vegetative and ripening periods, in the three varieties studied in detail. The time taken for brairding, for flower development, and for ripening, varies in the same order for the three varieties, because of variations in rate of growth due to temperature. The time taken for the rosette period, varies, not only with the rate of growth at a given season, but also according to the variety, and particularly with lateness of variety.

The later the variety, the greater the response of the plant in respect to a lowering of the "node-number," to a summer length of day, applied experimentally. In the field, however, owing to the effect of high temperatures, only for a short period in spring does the increasing length of day hasten flower initiation.

It was found that, in the late variety "Tallarook," flower initiation becomes variable, and then fails, when the minimum weekly temperatures rise above 50°F., and thus the vegetative period suddenly lengthens. The temperature level falls below this in April, but initiation is still prevented, and it is only in late July or early August that plants sown at any time in the previous mid-spring and summer form flower primordia. This failure to commence flower initiation under high temperatures, results in a much longer vegetative period than if variations in rate of growth were the only cause: under conditions preventing summer drought, several months extra grazing can thus be obtained from summer sowings after the critical date.

This may be due, either to a direct repressive effect of high temperature on flower initiation, with a consequent after-effect lasting several months after the temperature has fallen below "critical" level, or to the indirect effect of high temperature, owing to the necessity for a period of low temperature, as a prelude to the formation of flower primordia.

The mid-season variety—"Mt. Barker"—is comparable, except that the critical temperature level is about 53°F., and consequently the first sowing to result in a prolonged vegetative period, is later, and flower initiation is somewhat earlier in the following year—mid-June.

In the early variety, "Dwalganup," sowing throughout the year resulted in flowering all through, but a period of variable initiation occurs from January to March, associated with temperatures fluctuating above a level of about 67°F.

In the three varieties, the higher the number of the node at which the first flower is produced, compared with the typical number resulting from an early autumn sowing, the greater the degree of repression of initiation that has occurred.

Varieties sown at the same time, in localities ranging from Launceston to Sydney, showed variations in times of flowering related to the winter-spring temperature level of the locality; the late varieties were the least affected.

In observations on seed-production per plant, in relation to a dry season, certain varieties were superior in each maturity group, and there was no trend of reduced seed setting per inflorescence with lateness.

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Appendix I.—Districts from which the listed varieties of *T. subterraneum* have been obtained.

Variety.	Maturity.	Locality of Origin.
Dwalganup	E. 1 ..	Boyup Brook, Western Australia
Dwalganup White Seeded ..	E. 2 ..	Dwalganup, Western Australia
Muresk	E. 3 ..	Muresk, Western Australia
Second Northam	E. 4 ..	Northam, Western Australia
Mulwala	E. 5 ..	Mulwala, Corowa, Coreen, New South Wales; Quat Quatta, Victoria
Daliak	E. 6 ..	Western Australia
Northam	E. 7 ..	Northam, Western Australia
Reigert's White	E. 8 ..	Yarloop, Western Australia
Pink Flowered	E. 9 ..	Muresk, Western Australia
Yabba North	E. 10 ..	Yabba North, Victoria
Springhurst	E. 11 ..	Springhurst, Victoria
Baulkamaugh	E. ..	Baulkamaugh North, Victoria
Seaton Park	E.M. 1	Seaton Park, South Australia
Bacchus Marsh	E.M. 2	Myrniong, Smeaton, Myall, Windermere, Victoria
Burnley	E.M. 3	Burnley, Victoria
Madrid	E.M. 4	Madrid, Spain; Leige, France
Milton	E.M. 5	Milton, New South Wales; Seymour, Sebastopol, Winchelsea, Irrewillipe East, Victoria
Horsham	E.M. 6	Horsham, Victoria
Hill's Small	E.M. 7	Cobden, Mount Noorat, Irrewillipe East, Victoria
Samaria	E.M. 8	Samaria, Benalla, Violet Town, Victoria
Yea	M. 1 ..	Yea, Koriella, Victoria

APPENDIX I.—*continued.*

Variety.	Maturity.	Locality of Origin.
Edenhope	M. 2 ..	Edenhope, Goroke, Whitfield, Victoria
Mount Barker	M. 3 ..	Mount Barker, South Australia
Mount Barker White Seeded ..	M. 4 ..	Mount Barker, South Australia
Mount Barker Amber Seeded ..	M. 5 ..	Mount Barker, South Australia
Red-leaf	M. 6 ..	Upper Lurg, Victoria
Smeaton	M. 7 ..	Smeaton, Victoria
Casterton	L.M. 1	Casterton, Bemdigo, Victoria
Hexham	L.M. 2	Hexham, Nalinga, Casterton, Victoria
Mansfield	L.M. 3	Mansfield, Wangaratta, Docker's Plains, Kyaleram, Delatite, Toolborac, Benalla, Victoria
Derrinal	L.M. 4	Derrinal, Victoria
Benalla	L.M. 5	Benalla, Kyabram, Victoria
Berlin	L.M. 6	Berlin, Germany
Nangeela	L.M. 7	Nangeela, Bendigo, Victoria
Kyabram	L.M. 8	Kyabram, Victoria
Burnerang	L.M. 9	Wangaratta, Victoria
Pahantamu	L.M. 10	Pahantamu, New Zealand
Merino	L. 1 ..	Merino, Victoria
Macarthur	L. 2 ..	Macarthur, Victoria; Bothwell, Tasmania
Ruakura Selu.	L. 3 ..	Ruakura, New Zealand
Tallarook	L. 4 ..	Tallarook, Seymour, Bena, Korumburra, Romsey, Warncoort, Carisbrook, Warrion, Victoria; Tumbarumba, New South Wales
Wonigup	L. 5 ..	Bridgetown, Western Australia
Rostock	L. 6 ..	Rostock, Cambrai, Europe
Flinders	L. 7 ..	Flinders, Victoria
Wodonga	L. 8 ..	Wodonga, Victoria
Rouen	L. 9 ..	Rouen, France; Berlin, Germany
Phillip Island	L. 10 ..	Phillip Island, Monomeith, Victoria
Kyneton	L. 11 ..	Kyneton, Victoria
Bass	L. 12 ..	Bass, Beaconsfield, Tooradin, Mooroolbark, Yering, Glen Alvie, Woolamai, Yannathan, Loch, Monomeith, Caldermeade, Warragul, Bena, Leongatha, Victoria
White Seeded Bass	L. 13 ..	Burnley, Victoria
Ruakura Farm	L. 14 ..	New Zealand

APPENDIX II.—KEY TO VARIETIES OF *T. subterraneum* (ADAPTED FROM ULLMANN.)

A. PETIOLES SHORT TO MEDIUM-STALKED.

1. Peduncle little longer or shorter than subtending petiole—

(*a*) Runner mostly 10–15 cm. long, peduncle about as long as subtending petiole, head with 2–5 florets, burr the size of small hazelnut. The most usual form. Variety *normale* Rony, *typicum* Asch. & Gr.

(*b*) Plant small, runner mostly 3–8 cm. long; plant strongly hairy, leaves with felt-like hairs, peduncle much shorter than petiole or almost absent; head with 2–3 florets; burr the size of a pea; calyx often sparsely softly hairy, mostly red-coloured; sterile florets with shorter calyx teeth. Occasional in dry, stony places. Variety *brachychaetium* Guss. & Bertl. (2nd Northam) ?

2. Peduncle all or mostly much longer than subtending petiole. Plant lax, elongated, runner mostly 25–40 cm. peduncle 4 times longer than petiole; stipules long, pointed; head with 3–5 florets, burr the size of small hazelnut; corolla not noticeably veined. Only in Southern Medit. Districts. Variety *laxiflorum* Guss. (Wonigup ?)

B. PETIOLES OVER 10 CM. LONG.

1. Plant very vigorous; runner 25–55 cm. long, lax, almost virgate; leaflets large, 2.5 cm. long and 3 cm. wide, distinctly toothed; peduncle long, but only as long or shorter than petiole; head with 2–3 large florets; burr the size of a pea; corolla pinkish-striped; calyx teeth ciliate. Mostly in Southern Mediterranean districts, but often more northerly. "Plant worth investigation." Variety *oxaloides* Rony.

2. Like var. oxaloides, but with dark violet flowers; corolla 14–18 mm. long, 3–4 times as long as calyx teeth, which are longer than corolla tube. Palestine, on light, stony places, occurring with var. oxaloides. Variety *Tel-Aviviensis* Eig.

Occurrence of species—British Isles, France, Iberian Penin., Italy, including Islands, Balkan Penin., including Islands, Krim, Caucasus, Asia Minor, Persia, Syria, North Africa, Canary Islands, Madeira.

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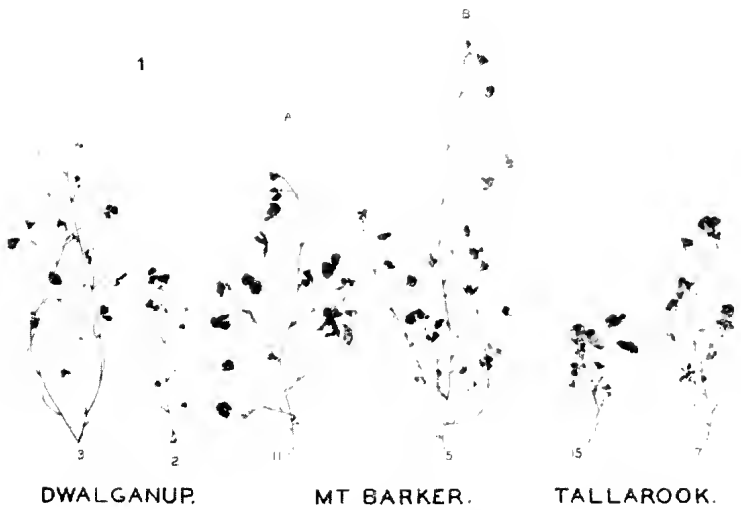

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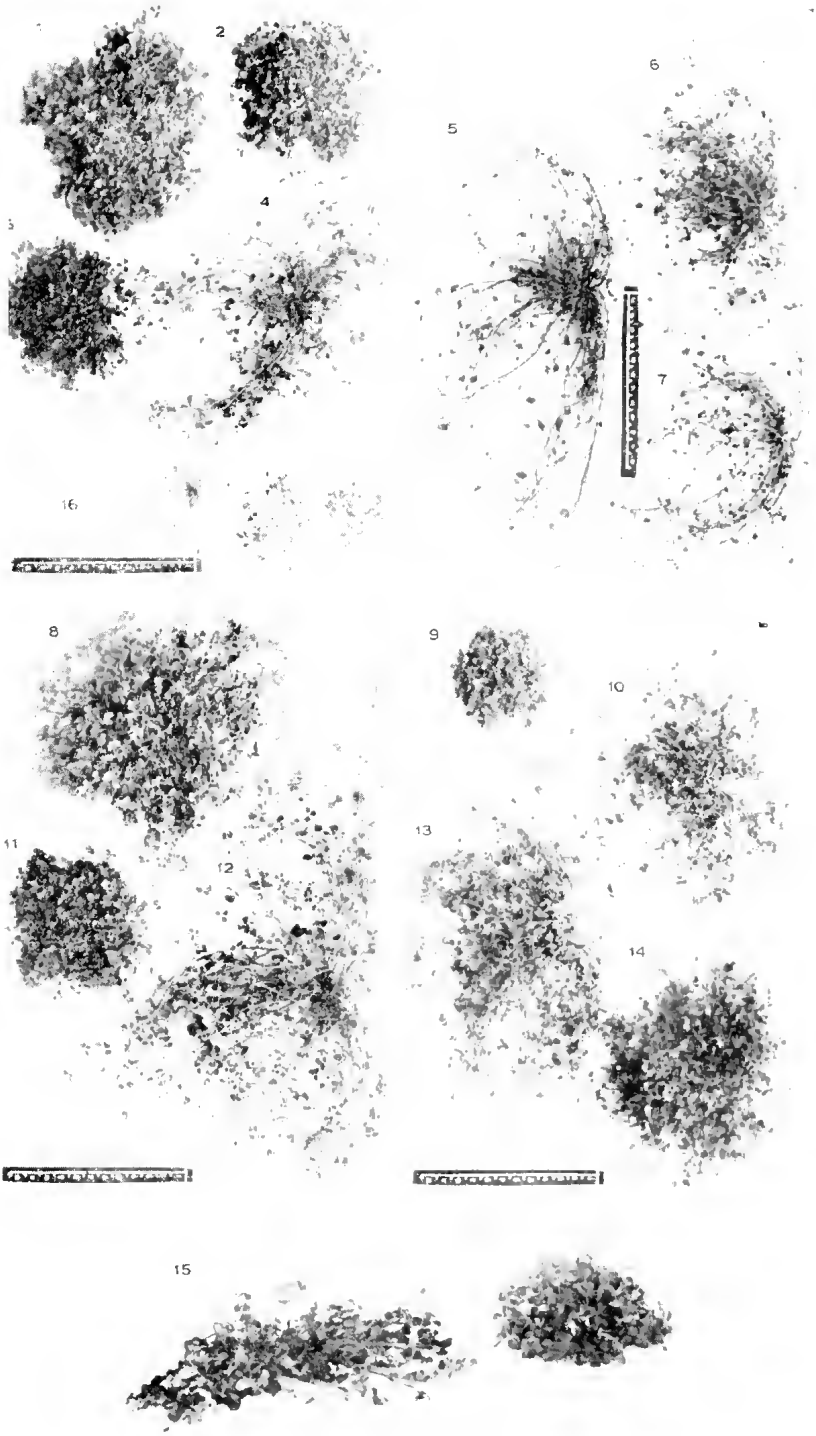

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Explanation of Plates.

Plate XVII.

(1) The effect of exposure to 15 hours daily illumination, on plants of "Dwalganup" (early), "Mt. Barker," (mid), and "Tallarook" (late) varieties, as shown by the node of first flower, on the basal runner from each variety. A—control, B—longday.

(2) Basal runners from a plant of "Dwalganup" (A), "Mt. Barker" (B), and "Tallarook" (C), to show the increase of laterals, developed with increase in number of node of first flower; two plants of "Mt. Barker" variety from a sward (D, E) and one from spaced plots (F), to show reduction in number of runners and laterals under competitive conditions.

Plate XVIII.

Plants of varieties from plots of Burnley Gardens showing range of growth-habit, in relation to maturity and to variety. Sown early April, photographed mid October. 1. Tallarook; 2. Merino; 3. Bass (late); 4. Burnley (early-midseason); 5. Springhurst; 6. Mulwala; 7. Dwalganup (early); 8. Nangeela; 9. Burnerang (late mid-season); 10. Bacchus Marsh (early mid-season); 11. Macarthur; 12. Wenigup (late); 13. Mt. Barker (standard mid-season); 14. Mansfield (late mid-season); 15. Plants of "Mt. Barker" (left) and "Burnerang" (right), photographed at an angle to show the "bunched" growth of "Burnerang" compared with the prostrate habit of "Mt. Barker"; 16. Plants of "Dwalganup," "Mt. Barker," and "Tallarook," sown mid-June, to show the relatively small size compared with the plants sown in April.

Plate XIX.

Some types of pattern on the leaf surface, due to variations in anthocyanin and crescent:—1. All leaf surface coloured red (Red Leaf); 2. Light green crescent with white arms and a narrow brown edging occurring on some leaves (Seaton Park). Section of stem showing variations in hairiness; 3. glabrous stem, peduncle and petiole (Reigert's White-seeded); 4. glabrous stem, hairy peduncle and petiole (Madrid); 5. hairy stem, peduncle and petiole (Mt. Barker); 6. hairy stem with appressed hairs (Muresk).

[Proc. Roy. Soc. Victoria, **53** (N.S.), Pt. II., 1941.]

Art. XIII.—*The Volcanoes of the Portland District.*

By ALAN COULSON, M.Sc.

[Read 12th December, 1940; issued separately 26th July, 1941.]

Introduction.

Underlying the dune sands and dune limestones of the Portland District are extensive basalt flows and tuff beds which represent the western margin of the great Western District lava field of Victoria. These igneous rocks are part of the Newer Volcanic Series, and the lava flows, with a few exceptions, consist of iddingsite-labradorite-basalts of the Malmsbury and Footscray types (Edwards, 1938). The vents from which they were extruded fall into three groups (fig. 1).

The Coastal Volcanoes: Cape Bridgewater, Cape Nelson, Cape Grant, Lawrence Rocks, and Julia Percy Island.

The Central "Sand-covered" Volcanoes: Mt. Kincaid, Mt. Richmond, Mt. Clay.

The Northern Volcanoes: Moleside Creek vent, Mt. Vandyke, Mt. Deception, the group of vents at Mt. Eckersley, and Mt. Eccles.

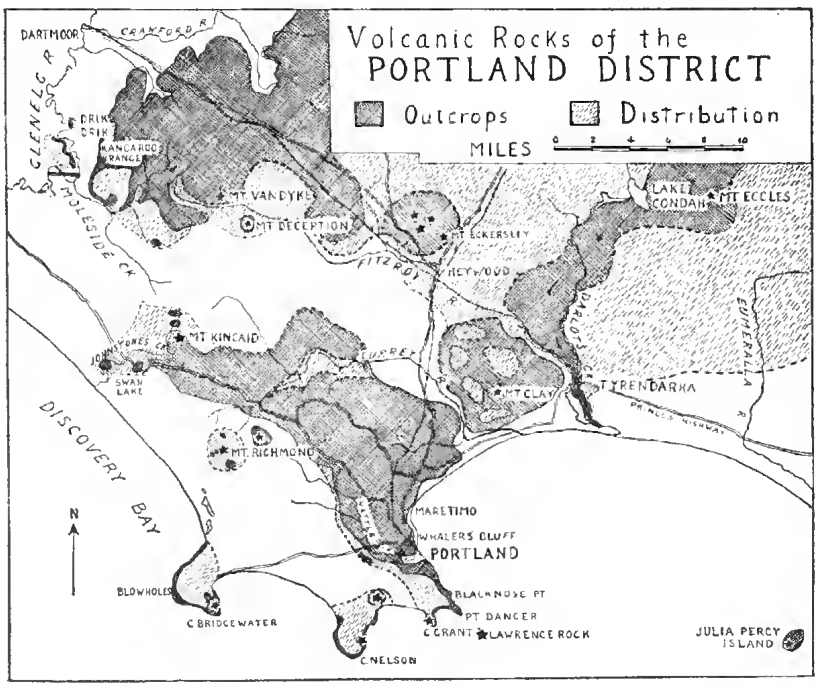

Fig. 1.

Difficulty was experienced in tracing some of the flows to their sources because of the change in texture of the rocks in the vicinity of the vents, and also because of the abundance of tuff associated with some of them.

Coastal Volcanoes.

Cape Bridgewater is a promontory composed of tuffs and basalt flows, overlain by dune sands and dune limestone. The steep eastern cliff-face, which rises to 450 feet above sea-level at the Stony Hill trig. station, provides a section through the composite volcano from which the igneous material came. As shown in fig. 2, two conduits connected with the surface flows of basalt are exposed, one between Bat Cave and Fisherman's Cave, and

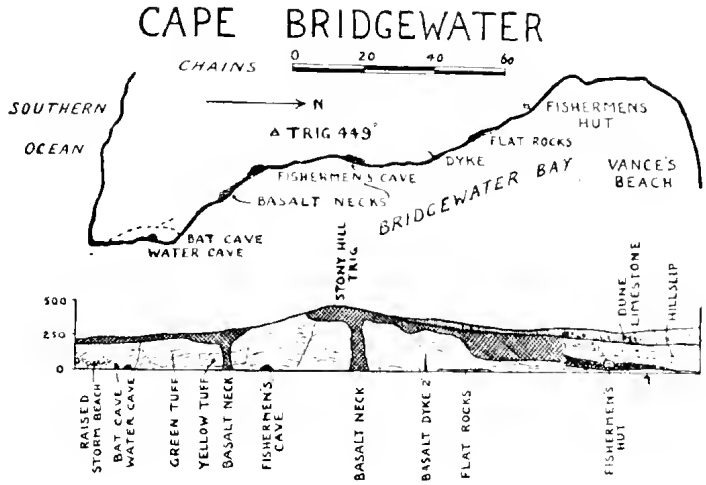

FIG. 2.

the other 30 chains east of Fisherman's Cave. The greater part of the cliff is formed by the undulating beds of tuff, containing scoria and lapilli, of the old volcanic cone. Numerous pebbles of Miocene limestone occur in the lower beds of tuff, but are found only occasionally in the higher beds; and masses of white and pink-stained quartz are embedded in the scoriaceous lava at the top of the vents. These fragments may have been detached from Palaeozoic sediments, which presumably underlie a cover of at least 2,000 feet of Tertiary limestone (as shown by the Portland bore), and probably a certain thickness of Jurassic sediments.

The basalt which was extruded from the more easterly vent, and forms Stony Hill, is dense and black, containing occasional phenocrysts of olivine. These are accompanied by microphenocrysts of labradorite (An_{60}) and diopsidic augite (2V greater than 45°), and are set in a microcrystalline groundmass of

pyroxene, iron ore, and felspar microlites. The augite tends to be glomeroporphyritic. The basalt from the westerly vent is dark grey, and minutely vesicular. It contains numerous phenocrysts of olivine, some very large, and occasional small laths of plagioclase (An_{60}). Some olivine crystals are unaltered, but others are almost entirely changed to iddingsite. The groundmass is very fine-grained, and consists of minute grains of pyroxene and olivine, felspar microlites, iron ore, and glass. A dyke 2 feet wide occurs at Cowrie Cove. It consists of tachylitic olivine-basalt.

The cliffs forming the western face of the Cape are composed of thick flows of basalt, separated by layers of scoriaceous basalt. Marine erosion has formed "blowholes" in places in the scoriaceous layers. The basalt is dark grey and dense, and consists of numerous microphenocrysts of olivine completely altered to iddingsite, and small laths of plagioclase (An_{60}) in a groundmass of plagioclase laths and abundant brown glass which has a "feathery" appearance owing to the presence of skeletal crystals of iron ore.

The basalt flows from the Cape Bridgewater vents are mostly covered by dune limestone.

Cape Nelson is another composite volcano whose structure is exposed in the cliff section facing Nelson Bay, between Black Bluff and Yellow Bluff (fig. 3). The cliffs rise sheer to a height

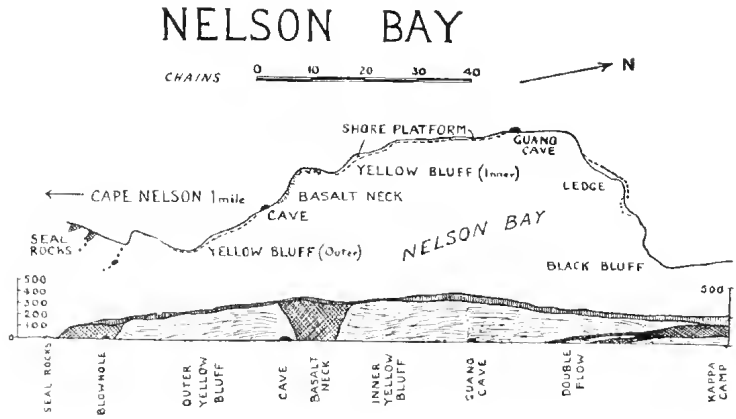

FIG. 3.

of 200–300 feet above sea-level, and are fronted by a narrow wave-cut bench. In the centre of the section is a funnel-shaped vent filled with scoriaceous basalt, and surrounded by beds of yellow tuff. The vent and the tuffs are capped with dune limestone.

At Black Bluff, low down in the projecting cliff face, there are two flows of basalt separated by about 4 feet of tuff. When followed eastwards, the upper flow, which is 5 feet thick, merges into the lower flow, which descends below water level. They are inaccessible, but what is probably the same flow increases in height to the east of Black Bluff, forming a single sheet of basalt about 50 feet thick near Kappa Camp, where it rests on 8 feet of tuff. Here the flow is an iddingsite-labradorite-basalt of the Malmsbury type. East of Kappa Camp, the basalt is cut off, presumably by a north-south fault, and the cliff consists of dune limestone down to sea-level.

This basalt probably had its source in the quarry reserve, Allotment 2, Section VII., Portland, where stone used for the Cape Nelson lighthouse was obtained. The basalt at the foot of the lighthouse (on the "Horseshoe") is also an iddingsite-labradorite-basalt of the Malmsbury type, and extends from the Seal Rocks at Yellow Bluff, to Old Shelly Beach on the west side of Cape Nelson. It is over 100 feet thick, and its base passes below sea-level. Patches of scoria occur in it, and it is overlain by dune limestone.

Cape Grant is of a similar nature. On its western side at "The Wells," four volcanic vents or necks are exposed in the cliffs (fig. 4) which are over 200 feet high. All four have walls of

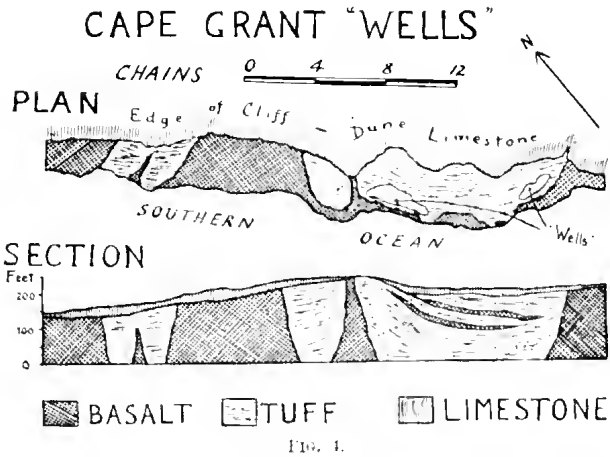

FIG. 4.

dense black basalt. The throats are filled with yellow tuff, scoria, blocks of basalt, and slightly metamorphosed blocks of Tertiary limestone. The largest vent, which is the most easterly, is 150 yards in diameter,

The material filling this vent is overlain by beds of scoria and thin irregular flows of basalt. The ash and scoria beds dip strongly westwards to the sea, indicating that the centre of the vent lies further inland, beneath the dune limestone.

The basalt forming the walls of these vents is dense and black. It consists of occasional microphenocrysts of olivine in part altered to serpentine, in a groundmass of abundant short laths and plates of zoned plagioclase (about Ab_{60}), aggregates of minute augite crystals, square grains of magnetite, and rods of ilmenite.

Lawrence Rocks, which are one mile off-shore from Point Danger and project about 80 feet above sea-level, have a basaltic foundation upon which rest beds of yellow tuff about 50 feet thick. Wave-cut benches up to 200 yards wide and 3 feet above water-level have been cut in the basalt.

Lady Julia Percy Island, 19 miles east of Portland, is a flat-topped island 120 feet high and one and a half miles in diameter, and is composed of boulder tuff, a series of olivine-labradorite-basalts, and iddingsite-labradorite-basalt of the Footscray type (Stach and McIver, 1936). The lava flows were derived from an adjacent vent, part of whose walls remain in the southern cliff of the island (Pinnacle Point).

The Central "Sand-Covered" Volcanoes.

The three domes of lava and tuff forming this group of volcanoes are covered not by dune limestone, but by younger sand dunes.

Mt. Kincaid, the most westerly of the three, rises to 664 feet above sea-level, and is covered by patches of dune sand to a height of 500 feet. The summit, which is free of sand, is composed of vesicular basalt. The flow from this volcano extends south-eastwards for 20 miles, as far as Portland. It is a vesicular, dark-grey, iddingsite-labradorite-basalt of the Malmsbury type. The olivine crystals are of two generations. The earlier-formed crystals occur as idiomorphic phenocrysts and are largely altered to iddingsite, while the later crystals, which belong to the groundmass, are only slightly iddingsitized, indicating that the iddingsitization occurred chiefly prior to the solidification of the lava. The flow averages about 100 feet in thickness, and passes below sea-level at Blacknose Point and Point Danger. Dune deposits occur only along its western margin.

It lies chiefly on Miocene limestone, but in the cliffs below "Maretimo" on the Dutton Way (North Portland), at Whaler's Bluff, and in places near Battery Point, an oyster bed, probably of Lower Pliocene age (Coulson, 1940) caps the limestones underneath the basalt. The undulations in the surface of the Miocene beds exposed in the cliffs between Battery Point and "Maretimo" cause the basalt to descend to sea-level nine times in this cliff section, with intervening places where the top of the Miocene is 40 feet above sea-level.

It may be noted that the numerous basalt boulders, up to a foot in diameter, brought up by divers working at the outer end of the long pier at Portland, are derived not from this flow, but apparently from the basalt of Lawrence Rocks. Boulders of this origin are associated with the basalt *in situ* along the beach from Battery Point to Pebbly Beach and Point Danger.

Mt. Richmond, 16 miles west of Portland, is a low broad dome covering an area of 5 square miles and rising to a height of 738 feet. The basalt, which is a fine-grained olivine basalt, is largely buried beneath a thick mantle of dune sands that reaches to the summit, and there do not appear to be any large flows away from the mount, although some may exist beneath the sand. The sands are arranged in a series of "tiers" encircling the volcano. The significance of this feature has been discussed elsewhere (Coulson, 1940).

Mt. Clay, 622 feet above sea-level, is another large dome rising above a basaltic plateau which is 400 feet above sea-level. It is a composite volcano, but all of its several vents extruded a similar variety of dense dark-grey olivine-basalt with a microcrystalline groundmass. A surface crust of vesicular basalt is present on the southern flanks. Large quantities of tuff were also ejected. A bore near the summit penetrated 130 feet in tuff. This tuff contains occasional blocks of chilled basalt.

On the southern slopes, at the Woolwash, the basalt formed a temporary barrier across the valley of the Surrey River. As a result the present valley of that river is constricted to a bottle-neck between Mt. Clay and the Gorae tongue of the Mt. Kincaid flow. Upstream from this point there has been a development of extensive alluvial flats at Heathmere and Heywood. At the base of the alluvium, there is almost everywhere a bed of buckshot gravel which averages 4 feet in thickness and rests directly on the eroded surface of the Miocene limestone. Near the Heathmere Railway Station a bore put down in 1894, in Allotment 2, Section VII., of Bolwarrah, by the Mines Department, passed through 7 feet of alluvium and buckshot, and then entered Tertiary limestone. It was still in Tertiary limestone at 1,505 feet, when it was abandoned.

The Mt. Clay basalt does not appear to pass below sea-level. Where its base is exposed it rests on the Tertiary limestones at about 60 feet above sea-level; and on the north side of the Mount, in Section 16, of Narrawong, tachylytic basalt rests on *Ditrupa* limestone (Miocene) at about 60 feet above river level.

The Northern Volcanoes.

Moleside Creek: Volcanic agglomerate outcrops in the great bend of the Glenelg River, near Moleside Creek. The outcrop extends for a mile in an east-west direction, crossing the river at three points, as shown on the geological parish plans of Kinkella and Kentbruck. Between and beyond these points it is

hidden under sand. The agglomerate consists of lapilli, fragments of metamorphosed Tertiary limestone, and fragments of slaggy basalt, which are cemented together by black, vesicular basaltic glass. It rises to a height of 60 feet above river level, and appears to have formed a barrier in the path of the Glenelg, so that it may have been a contributing factor to whatever caused the river to take its great westerly bend at this point. The agglomerate may infill a fissure.

On the south side of the Glenelg in the parish of Warrain, and close to its boundary with the parish of Kentbruck, a basalt dyke 4 feet wide has been noted by the Geological Survey. It is a much decomposed olivine-basalt.

On the west bank of the Glenelg, north of Moleside Creek, a flow of microporphyritic olivine-basalt about 5 feet thick occurs at the base of the dune limestones and sands, and overlies the Miocene limestones, which rise here to 100 feet above river level.

This rock appears to be identical with that capping the Kangaroo Range on the eastern bank of the Glenelg at a height of 400 feet. This similarity, and the difference in level of the two outcrops suggests that in this part of its course the Glenelg follows a north-south fault, as postulated by Foster (1929) in a section accompanying his geological map of the parish of Balrook, though this section does not agree with that drawn by Keble (1928) for the adjacent parish of Drik Drik to the north. Keble shows the "fault" as a cliff section. Foster based his section on the evidence obtainable at a large sink hole in Allotment 35, parish of Balrook. On the east side of the sinkhole, the Kangaroo Range basalt is exposed overlying Miocene limestone, while on the west side there is a boulder bed surmounted by dune limestone which dips at 30°N. and is about 55 feet thick. It rests unconformably on the boulder bed which is at least 20 feet thick. The boulders consist of sub-angular blocks of decomposed basalt, up to 12 inches in diameter, and angular blocks of Tertiary limestone up to 3 feet in diameter. The limestone is indurated, but does not appear to be volcanic ejectamenta. The blocks occur in a reddish-brown sand which contains only Miocene fossils. Mr. W. J. Parr has identified the following foraminifera from the sand:—

Dentalina inornata d'Orbigny.
Lagena sp. aff. *orbignyana* (Segeuza).
Globigerina bulloides d'Orbigny.
Globigerina dehiscens Chapman, Parr and Collins.
Cibicides sp.
Carpentaria rotaliformis Chapman and Crespin.
Elphidium crispum (Linné).
Operculina victoriensis Chapman and Parr.

Mr. Parr searched for, but failed to find, forms common to the dune limestone, such as *Discorbis dimidiatus*. Presumably, therefore, the boulder bed is a pre-dune-limestone talus at the

foot of a cliff of Miocene limestone surmounted by basalt. There is nothing to indicate whether it is talus from a river cliff or from a fault scarp. Exploration of a tunnel-like cave which connects this sinkhole with others 400 yards to the north, shed no light on this point. The cave is 30 feet high and 4 feet wide at the top, broadening to 10 feet at the bottom. A small underground stream runs through it. To the north the tunnel is in Miocene limestone, while to the south it is blocked by fallen blocks of Pleistocene dune limestone.

If the fault exists, as the levels of the basalt flows would indicate, it is presumably post-basaltic but pre-dune-limestone in age.

Mt. Vandyke (Good Hill) is a point of eruption 606 feet high. A flow of felspathic basalt issued from it, and spread out to the north and west for several miles. Its full extent is hidden by thick forest in the parish of Cobboboonee, but it appears to overlie the Kangaroo Range basalt. The rock is a dark-grey colour with abundant large white felspar and olivine phenocrysts, and bears some resemblance to the type of basalt forming the Stony Rises at Pirron Yallock (Skeats and James, 1937). A similar rock occurs at West Gorae, one and a half miles east of Mt. Richmond, in Allotment 15, Section 9, parish of Mouzie, where it forms a separate hill, probably a point of eruption, about 325 feet high. In this section it is an iddingsite-andesine-basalt of the Ballan Type (Edwards, 1938).

Mt. Deception (524 feet) is three miles east of Mt. Vandyke, and the Fitzroy River runs between them. Mt. Deception consists almost entirely of tuff with a few blocks of slaggy basalt. No flow could be traced from it.

The Mt. Eckersley Group of four volcanic hills comprising the Oakbank Estate, north-west of Heywood, shows considerable variation in the structure and composition of the several hills. Mt. Eckersley proper, or Bell's Hill (537 feet) is largely composed on tuff, which is well exposed in an old quarry near the summit. Occasional blocks of finely vesicular basalt occur in the tuff.

Sugarloaf Hill is composed of a grey compact iddingsite-basalt which is exposed in a quarry in Allotment 3, Section 3, parish of Drumborg. The third hill in Allotment 9, parish of Drumborg, north-west of Heywood Cemetery, is composed of a black, vesicular, fine-grained iddingsite-basalt, but the flow which issued from it to the west is not vesicular, and the olivine in it shows no trace of alteration to iddingsite. A coarser-grained iddingsite-basalt occurs in Allotment 7, Section 4, parish of Drumborg, immediately north-west of Heywood Cemetery.

The fourth hill, in Allotment 7, parish of Drumborg, consists chiefly of tuff with an occasional block of chilled basalt.

Mt. Eccles (584 feet) is probably the most recent point of eruption in the area. The flow from it filled a valley running to the sea, and divided the waters of the Fitzroy River and Darlot's Creek from Ettrick to Tyrendarra. In the vicinity of Tyrendarra and Homerton the infilled valley had been eroded in dune limestone (Hills, 1939; Coulson, 1940), so that this basalt is probably of Recent age. Throughout its length it has developed small stony rises and lava blisters, and numerous lava caves occur within it, similar to those described by Skeats and James (1937) in other parts of Western Victoria. In damming back Darlot's Creek, the flow gave rise to the Condah Swamp (Hills, 1939).

Conclusion.

From the foregoing brief descriptions, it will be seen that the basalts of the Portland District have undergone very little differentiation and are generally similar to the undifferentiated basalts of the Newer Volcanic Series elsewhere in Victoria. The eruptions which gave rise to them appear, however, to have produced a much greater amount of tuff than was developed in Central Victoria. In this respect they resembled the eruptions of the Colac-Camperdown District, where tuffs are equally abundant. The period of extrusion seems to have been of considerable duration, extending possibly from the Pliocene (Mt. Kincaid flow) through to the Recent (Mt. Eccles flow).

Acknowledgments.

My thanks are due to Messrs. W. J. Parr and F. S. Colliver for the identification of fossils; to Mr. G. B. Hope for the loan of instruments; to Messrs. F. E. Levy, W. C. Hedditch, B. O. Squire, and the Mines Department, for supplying maps; and to Dr. A. B. Edwards, for help with the petrography.

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[Proc. Roy. Soc. Victoria, 53 (N.S.), Pt. II., 1941.]

Art. XIV.—*The Crinanite Laccolith of Circular Head, Tasmania.*

By A. B. EDWARDS, Ph.D., D.I.C.

[Read 12th December, 1940; issued separately 26th July, 1941.]

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Introduction.

Circular Head is a prominent feature of the coast of North-West Tasmania well known both on account of its striking shape (Edwards, 1941) and its history. It owes its highly descriptive name to Bass and Flinders, who sighted it in December, 1798. Flinders (1814) describes is as "a cliffy hump, much resembling in form a Christmas cake, joined to the main by a sandy isthmus;" and in the Hobart Town Almanac for 1831 it is referred to as "that curious rock (which) stands like a huge round tower or fortress, built by human hands, which stretching out to sea, as if from the middle of a bay, is joined to the land by a narrow isthmus." It was here that the Van Dieman's Land Company established the first settlement in the North-West, in 1826.

As described elsewhere (Edwards, 1941) the Head is a tied island, joined to the main part of Stanley Peninsula by a Y-tombolo, which in 1826 still enclosed a marshy lagoon. The lagoon has been drained and converted into pasture land. The Head itself is composed of an igneous rock of a type unusual to Tasmania, and specimens submitted to Rosenbusch were described by him as trachydolerite (Twelvetrees, 1902).

Circular Head appears to be the remains of a small, steep-sided laccolith. As its name indicates, it is more or less circular in plan, with diameters between 800 and 900 yards. It consists of gigantic columns of igneous rock, 4 to 6 feet in diameter, and rising vertically to a height of 487 feet above sea-level. These columns are exposed in sheer cliffs, several hundred feet high, notably on the northern and south-eastern sides, with a fringe of steeply sloping scree around their bases. Inspection of the sea-bed from the top of the cliffs shows that a dark fringe of scree forms a ring of uniform width round Circular Head on all sides exposed to the sea, and no extension of the igneous rock exists

in any of these directions. Similarly, on the landward side where the scree slopes are more gentle, because they are not so subject to erosion, there is clearly no continuation of the rock towards the main ridge of Stanley Peninsula.

On the north-western side, on the beach below the Stanley Cemetery, the scree overlies soft mudstones and grits, which are exposed in the wave-cut bench. These sediments, which are presumably of Permo-Carboniferous age, judging by their texture and disposition, dip at about 30°N., and underlie the whole of Godfrey's Beach, since they also occur in the wave-cut bench at the north-western end of the beach. Similar sediments outcrop on the southern side of Circular Head, between the old wharves and the new, where they are visible at low tide. Much weathered sediments overlain by scree deposits are exposed in a cutting opposite the Harbour Master's Office, at the entrance to the wharves; and behind the adjacent timber yard, where the talus deposits have been completely removed, and a quarry has been cut to provide extra platform space, the sediments are exposed as an uneven surface sloping down towards the north-east beneath the igneous rock. The contact appears to be more or less conformable, while the sandy sediments are very little metamorphosed beyond induration for a few inches below the contact.

At the contact, and for a few feet above, the igneous rock is chilled, and has an almost glassy texture. When followed upwards, the grain size increases, and the ferro-magnesian minerals, particularly the pyroxene, become more prominent. At a height of 100 to 150 feet above the chilled base, the pyroxene crystals are 2 to 3 mm in diameter, and show a distinct concentration. They project on weathered surfaces, and give the rock a spotted appearance. Rising still higher up the columns the coarse grain size is maintained, but the proportion of pyroxene decreases, until near the top felspar appears to be the dominant constituent. This progressive change can be observed on all sides of the Head.

The upper surface of the headland is not flat, as appears from a distance, but slightly undulating. Two small valleys combine to form a hanging valley 80 feet deep, and 320 feet above sea-level, on the southern side.

It is presumed, therefore, that Circular Head represents the core of a small, dome-shaped laccolith. Subaerial erosion has removed the roof and wall rocks, and destroyed the original chilled top of the laccolith. Marine erosion of the soft Permo-Carboniferous sediments underlying the laccolith has undermined the floor of the laccolith around its margins, causing the igneous columns to collapse. In this way the walls of the remaining portion of the laccolith have steepened and increased in height as they have retreated. The undermining process must have begun subsequent to the extrusion of the Green Hills basalt flow which

forms the main ridge of the Stanley Peninsula, and is still in progress. The various stages in the development of the headland are shown diagrammatically in fig. 1.

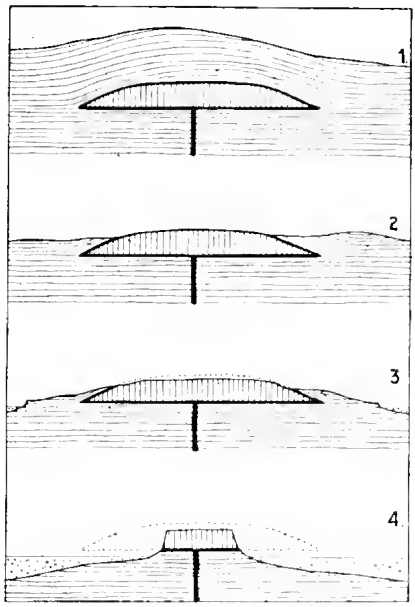

Fig. 1.—Diagrammatic representation of the development of Circular Head. 1. Intrusion of laccolith; 2. Unroofing; 3. Subaerial erosion; 4. Present stage, after undercutting by marine erosion.

Petrology.

The differentiation noted in the field is readily apparent when the proportions of the ferro-magnesian and other minerals in a series of specimens taken at successive levels from top to bottom of the laccolith are compared by micrometric analyses of thin sections (see Table I.).

Table I.—Variation in Mineral Composition with Height above Chilled Base.

Height Above Chilled Base.	Olivine.	Pyroxene.	Iron Ore.	Felspars, Groundmass, &c.
Feet.	Per cent.	Per cent	Per cent	Per cent
440 (summit) ..	6·8	13·9	3·8	75·4
420	6·4	13·1	3·9	76·6
390	4·4	16·2	3·6	75·8
350	15·7	20·7	4·5	59·0
320	11·8	14·1	4·0	70·1
290	14·7	17·9	3·8	63·6
230	10·9	17·7	4·7	66·7
180	14·1	18·8	4·0	63·7
130	6·5	27·3	4·0	62·1
100	21·1	18·6	3·0	57·3
70	24·9	21·5	4·2	49·4
20	17·6	15·9	4·0	62·6
0 (base) ..	11·5	0·5	Nil	88·0

Comparison is aided by plotting the mineral percentage against elevation above the contact of the chilled base with the sediments, as has been done in fig. 2A. This shows that there is a marked concentration of the ferro-magnesian minerals in a narrow zone immediately above the "floor" provided by the chilled base of the laccolith. Above this zone the ferro-magnesians decrease steadily with increasing height above the "floor." The concentration of the ferro-magnesians in the lower part of the laccolith has displaced the felspathic and felspathoid constituents into

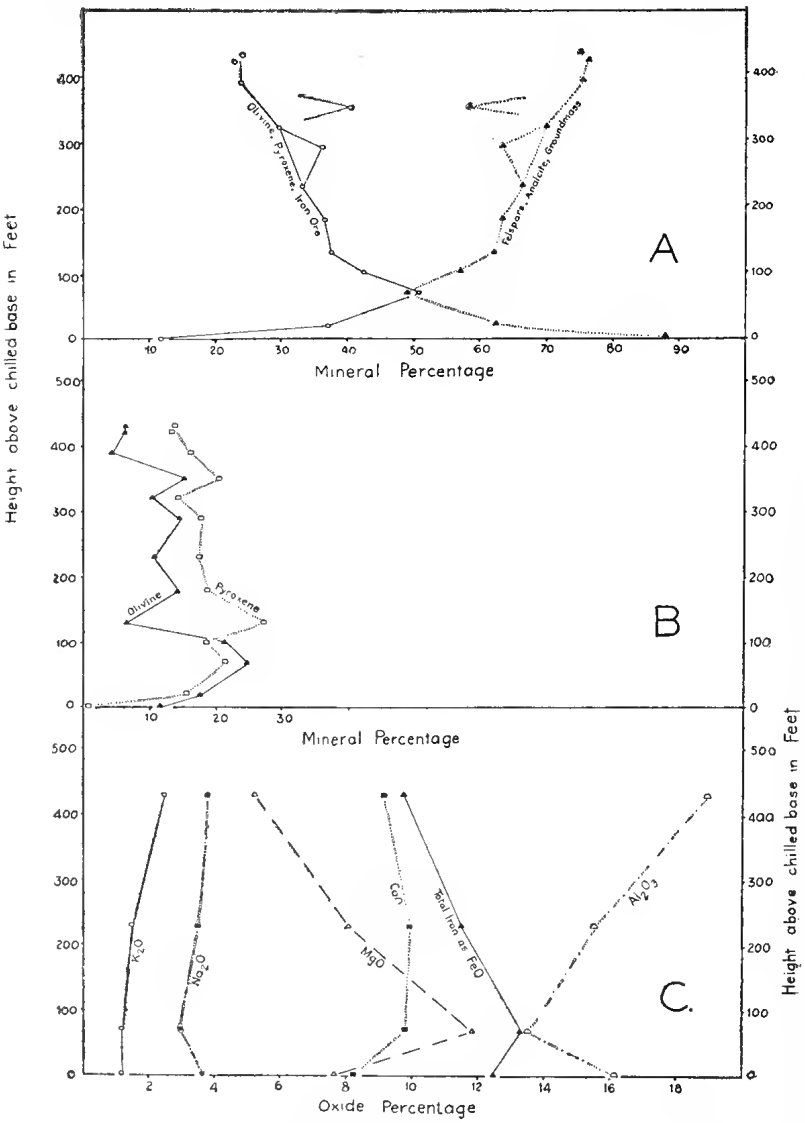

FIG. 2.—Variation profiles of the Circular Head Laccolith. A and B, Mineral Profiles; C, Oxide Profiles.

the upper levels. In fig. 2B, the ferro-magnesian graph of fig. 2A is analysed in terms of the two chief mafic components, olivine, and pyroxene. The olivine had commenced to crystallize prior to the emplacement of the magma, as is shown by its presence in the chilled base, whereas the pyroxene had not. As a result, the accumulation of olivine on the "floor" began before the pyroxene began to accumulate. Moreover, although the earlier-formed pyroxene formed as phenocrysts, and tended to sink, the later-formed pyroxene tended to form ophitic intergrowths with the plagioclase. This had the effect of buoying up such pyroxene. Some olivine, also, was prevented from sinking by becoming enclosed within the ophitic pyroxene. As a result, the gravitation of the pyroxene was less complete than that of the olivine, while the level of greatest accumulation of pyroxene extends above the level of greatest accumulation of olivine, and is not so sharply defined. Further, the sinking of the ferro-magnesian minerals did not proceed uniformly throughout the laccolith. As shown in fig. 2A, in some specimens the ferro-magnesian content greatly exceeds the general tenor of the surrounding rock, no doubt as a result of the "buoying up" factors noted above. In others, in which there is an unusual concentration of analcite (Table III.), there has been excessive removal of the ferro-magnesians probably because viscosity was reduced by the presence of abundant mineralizers. A number of other factors, such as the effects of convection currents close to the walls of the laccolith, may have contributed to these local variations.

The differentiation within the laccolith is equally well demonstrated by a series of chemical analyses of specimens from various levels, as is shown by Table II., and fig. 2c.

TABLE II.—CHEMICAL ANALYSES AT VARIOUS LEVELS IN THE LACCOLITH.

——	1.	2.	3.	4.	5.
SiO_2	44·75	43·35	45·70	46·15	48·05
Al_2O_3	16·15	13·50	15·52	18·95	21·33
Fe_2O_3	4·52	2·62	3·75	3·68	4·60
FeO	8·35	10·91	8·11	6·41	4·96
MgO	7·68	11·81	8·04	5·20	2·03
CaO	8·20	9·85	9·05	9·15	6·10
Na_2O	3·68	3·02	3·51	3·79	5·18
K_2O	1·18	1·18	1·51	2·43	4·28
H_2O	0·25	0·15	0·19	0·20	0·20
H_2O	1·74	0·71	0·70	1·49	1·72
CO_2	Nil	Nil	Nil	Nil	Nil
TiO_2	2·25	2·25	2·35	1·65	1·95
P_2O_5	0·71	0·83	1·08	0·50	0·25
MnO_2	0·11	0·10	0·10	0·10	0·12
	99·57	100·34	100·54	99·70	100·77

1. Chilled base at contact, behind timber yard, main wharf.
2. Olivine-rich layer, 70 feet above chilled base, same locality.
3. Two hundred and thirty feet above the chilled base, north-western side.
4. Summit, at 187 feet, or 440 feet above chilled base.
5. Nepheline-rich phase of the crinanite, not *in situ*.

ANALYST. A. B. EDWARDS.

The magnesia content of the analysed specimens shows a sharp increase in the olivine-rich layer, and then decreases in the higher layers. Total iron behaves similarly, though the change from specimen to specimen is not so large. The variation in lime content is more complex in that whereas some lime was carried downwards by sinking of pyroxene, some lime was also carried upwards by the displacement upwards of the plagioclase in the residual magma. This movement of the plagioclase is brought out more clearly by the changes in the alumina and alkali content. These are more or less reciprocal to the changes in magnesia content.

The nearest approach to the original magma from which the Circular Head laccolith was derived, is provided by the little differentiated chilled base, and the chemical analysis of this phase (No. 1) indicates that it was a fairly typical undersaturated olivine-basalt magma (in the sense of Kennedy, 1933). The analyses closely resemble those of crinanites, except that they contain rather more potash (Walker, 1934). The potash content is not great enough, however, to enable the rock to be classified as teschenite, nor is the soda sufficiently high for this.

Petrography.

Chilled Base.

The chilled base at the contact with the underlying sediments is an almost cryptocrystalline rock, consisting of idiomorphic microphenocrysts of olivine, 0.1 to 0.2 mm. in diameter, set in a groundmass of minute grains of iron ore, olivine, prisms of pyroxene, microlites and minute twinned laths of plagioclase, needles of apatite, and abundant colourless glass. The olivine is partially altered to iddingsite, leaving a core of unaltered olivine, and a narrow rim of fresh olivine encloses the iddingsite. Where the olivine occurs as a groundmass constituent it generally encloses a minute core of iddingsite. Occasional microphenocrysts of moderately violet titanaugite occur, usually smaller than the olivine crystals. The bulk of the pyroxene, however, is present as minute violet prisms in the groundmass. These show extinction angles up to 45 degrees on the prism axis, and are presumably augite. The felspar microlites show practically straight extinction, while the laths with lamellar twinning extinguish at angles up to 15 degrees in the symmetrical zone. This indicates that the plagioclase is a basic oligoclase, of composition about Ab_{70}, which is borne out to some extent by the high soda content of the analysis of this rock (Table II., No. 1). Presumably the colourless glass also approaches this composition.

The most striking feature in the thin sections is the occurrence of numerous almost circular vesicles, 0.1 to 0.2 mm. in diameter, filled with acicular growths of what appears to be natrolite.

Twenty feet above the actual contact, the appearance of the rock has changed greatly. The olivine microphenocrysts average about 0.5 mm. in diameter, although some are as long as 1 mm. They have gathered into clots, and while they retain something of their original idiomorphic outline, they tend to be rounded and embayed. The iron ore grains are fewer, but coarser, and are associated with the clusters of olivine crystals. The interspaces between the clusters of olivine and iron-ore are divided up by long narrow plagioclase laths (averaging about 0.5 x 0.02 mm.), and sometimes larger (1.0 x 0.2 mm.), and the triangular interspaces between the laths are filled with prisms of violet-brown pyroxene, frequently gathered into rosettes or stellate groups. Patches of analcite, sometimes enclosing acicular natrolite, also occur in these interspaces. The plagioclase laths show extinction angles up to 30 degrees in the symmetrical zone, so that they consist of labradorite, of a composition about Ab_{45}. Even the apatite needles have partaken of the general increase in grain size.

The Olivine-rich Layer.

The rock composing the layer of olivine accumulation, about 70 feet above the chilled base, shows a further change in texture. The titanaugite crystals have grown in size to prisms 0.5 x 0.2 mm. and have gathered into clusters, often preserving the stellate arrangement observed in the more crystalline part of the chilled base. In these clusters the titanaugite crystals are usually associated with the numerous coarser-grained, but rounded, crystals of olivine, and relatively coarse-grained crystals of iron-ore. Very little pyroxene remains in the groundmass, which consists essentially of plagioclase laths, crowded together, a little interstitial orthoclase, and analcite. The plagioclase is a basic labradorite (Ab_{35}), and has suffered partial analcitization. The individual laths are relatively small compared to the other minerals. The analcite in some of the interstices is intergrown with numerous more or less radially arranged inclusions of a purplish to brownish substance, which is generally opaque, and gives the impression of being extremely thin plates of titaniferous iron ore. Some of the brown inclusions, however, are very weakly birefringent, and show a minute cleavage pattern similar to that in the pyroxene, suggesting that it consists of thin plates of pyroxene. Some of the intergrowths are more or less granophyric in appearance.

At 100 feet above the chilled base the rock is essentially similar. The olivine, however, has undergone partial iddingsitization, and a wide rim of fresh olivine encloses the iddingsitized portion. The junction between the iddingsite and the outer olivine is sharply defined, but where cores of olivine are also present, the junction of the iddingsite with this inner olivine is fibrous and irregular. The felspar is still restricted to the groundmass, and

is chiefly basic labradorite (Ab_{35}), but a small amount of interstitial orthoclase is also present. The apatite crystals have become noticeably coarse-grained, and appear as hexagonal cross sections and as large prisms.

ANALCITE-OLIVINE-TITANAUGITE-DOLERITE.

The bulk of the laccolith, the upper 320 feet, is composed of analcite-olivine-titanaugite-dolerite, in which the proportion of olivine decreases with elevation above the chilled base. In the uppermost 100 feet the olivine constitutes less than 10 per cent. of the rock, except in localized patches, and the titanaugite, which is the dominant ferro-magnesian, becomes increasingly ophitic towards the plagioclase, so that in the uppermost 50 feet of the laccolith the rock may be regarded as a true crinanite. Its richness in potash, however, reveals affinities with the teschenites.

The chief distinction between the dolerite and the olivine-rich layer is the increased coarseness of grain-size in the dolerite. Individual crystals of olivine and titanaugite frequently attain a diameter of 2 mm. or even larger, and the plagioclase laths show a comparable growth in size. The olivine has frequently undergone partial alteration to iddingsite, and consists of a core of olivine, mantled by a zone of iddingsite, which is enclosed in turn by a narrower rim of fresh olivine. The outer junction of iddingsite and olivine is sharply defined, but the inner one has a fibrous character, as in the upper part of the olivine layer. The titanaugite is distinctly pleochroic, with X = yellow, Y = deep violet, Z = pale violet, and has a $(+)$ $2V$ about 60 degrees. The large crystals are frequently zoned, the marginal zones being a deeper violet than the inner ones. They sometimes show twinning and hour-glass structure. The titanaugite tends to enclose the smaller olivine crystals, and this habit becomes more marked with increasing height above the base. In some instance the olivine so enclosed has been completely altered to iddingsite, presumably prior to its enclosure by the titanaugite. The ferro-magnesian minerals and the iron ores have segregated into clusters, and the plagioclase laths form a triangular pattern in the interspaces. The plagioclase is basic labradorite (Ab_{35}). Patches of interstitial orthoclase are associated with it, and these appear to grow larger and more numerous near the top of the laccolith.

The proportion of analcite varies irregularly. It occurs in the interstices between the plagioclase laths, and frequently invades the plagioclase along cleavage planes and cracks. Where it makes contact with crystals of titanaugite there is a tendency for a narrow partial rim of aegirine-augite, or even aegirine to develop. Radial intergrowths of brown and purplish material such as were noted in the olivine-rich layer continue to be present in the analcite, and the coarse apatite prisms become a prominent feature in the sections. Sometimes, either owing to irregular crystallization or to partial resorbtion they form "atoll" growths.

Soda-rich Variations.

Although no variety more soda-rich than the crinanite of Analysis No. 4, Table II., was observed *in situ*, a number of lighter coloured boulders were observed in the screes and the beach deposits on either side of Circular Head. Specimens of these boulders proved to be much more sodic than the normal rock, and were found to contain notable amounts of analcite, and natrolite, and even a little nepheline.

The ferromagnesians form only a small part of these specimens. Olivine is subordinate to titanaugite, and both are present only as small crystals. The olivine is often enclosed in the pyroxene, and consists of a core of iddingsite enclosed by fresh olivine. The titanaugite has a (+) 2V about 60 degrees, and is invariably ophitic towards the plagioclase (Ab_{40}), which tends to occur in clusters of long narrow laths separating areas in which they are intergrown with the ferromagnesians. The titanaugite is commonly altered at the margin to a narrow rim of aegirine. Analcite is prominently developed, and has attacked the plagioclase to a considerable extent, but has not affected the orthoclase, which occurs relatively abundantly in the interstices of the plagioclase areas. Natrolite forms acicular growths in elongated and irregular-shaped areas of a vesicle-like character, and occasionally a corroded crystal of nepheline, preserving much of its idiomorphic outline, is present. Coarse prisms of apatite are numerous in association with the analcite and natrolite.

Nepheline-rich Phase.

A specimen still richer in soda occurs in the collection of the Geological Survey of Tasmania (No. 288). Chips of this specimen sufficient for analysis were placed at my disposal through the kindness of Mr. F. Blake, Acting Government Geologist of Tasmania, and the analysis is shown in Table II., No. 5, from which it will be seen that not only soda, but potash also, is concentrated in this specimen.

The rock has a greyish, weathered appearance in hand specimen, and is spotted with small irregular-shaped areas of zeolites, occasional porphyritic felspars 5 mm. long, and laths of pyroxene. On roughly polished surfaces it shows spherical intergrowths of radially arranged felspar and titanaugite. Thin sections reveal occasional small crystals of olivine, extensively altered to iddingsite and iron ore, but preserving their idiomorphic outline to some extent. The dominant ferromagnesian, however, is titanaugite, which occurs chiefly in relatively small crystals, and also forms graphic intergrowths with the analcitized plagioclase. It frequently shows a passage through aegirine-augite to aegirine at the margin. The aegirine rims are often as wide as the titanaugite core, and the transition zone is marked by precipitated iron ore. Individual crystals of aegirine also occur through the

rock, though in much less abundance than the titanaugite. Plagioclase and orthoclase are present in more or less equal proportions. The plagioclase is labradorite (About Ab_{45}), and tends to occur as clusters of radially arranged laths. The orthoclase occurs as clear, broad areas filling the intersertal spaces and enclosing most of the other minerals. As shown in Table III. below, analcite and natrolite constitute about 16 per cent. of the rock, while nepheline forms about 8.5 per cent. of it. The nepheline occurs in numerous large rectangular and hexagonal crystals, which are somewhat corroded, and are veined by the analcite. It readily takes a stain with methylene-blue, using the method described by Shand (1939), but is not zoned. Coarse crystals of apatite, almost large enough to be classed as microphenocrysts, continue to be numerous, and the doubtfully identified brown to purplish material, found intergrown with the analcite throughout the laccolith, is also present. A little brown to emerald-green glass is also present, but iron ores are few, though coarse-grained. A micrometric analysis of several sections gave the following approximate composition:—

Table III.

Mineral.	Volume.
	%
Nepheline	8·6
Analcite, &c.	16·1
Plagioclase	34·8
Orthoclase	30·0
Titanaugite	4·6
Aegirine	2·8
Olivine	2·6
Iron ore	0·5
	100·0

Differentiation Processes.

The chief factor operating in the differentiation of the Circular Head laccolith appears to have been the differential sinking of the ferromagnesian minerals under the influence of gravity. The concentration of plagioclase in the upper levels was due to the reciprocal displacement upwards of the residual liquid by the sinking ferromagnesians.

The local concentrations of alkali-rich minerals call for a different explanation. The presence of corroded nepheline crystals, interstitial orthoclase, and titanaugite altered to aegirine proves that the concentrations of alkalis developed prior to complete solidification, though much of the analcite and natrolite may be of autopneumatolytic origin. Since the orthoclase occurs through the laccolith in minute interstitial patches, as one of the

last minerals to crystallize, it is presumed that these local concentrations of alkaline minerals represent small pockets of the final residual liquid of the magma trapped in the otherwise more or less solidified mass. It may be noted in this respect that the plagioclase in the most rapidly chilled part of the laccolith base has the composition of oligoclase (Ab_{70}), while the plagioclase throughout the more slowly cooled part of the laccolith is labradorite (Ab_{35-45}). Hence, although sufficient soda (and potash) was present to convert the bulk of the labradorite to oligoclase, it failed to enter into the composition of the plagioclase. Instead it made its appearance as analcite, and so far as it was not all used up in this mineral, it must have entered into the final residuum of the magma.

The richness of the magma in mineralizers indicated by the abundance of analcite provides an explanation of the unusual occurrence of iddingsite. Previously iddingsite appears to have been recorded only from extrusive and hypabyssal rocks (Ross and Shannon, 1925). Its mode of occurrence is closely comparable with that of iddingsite formed during the actual process of extrusion in certain Victorian basalts, where a temporary concentration of mineralizers led to formation of iddingsite, with a subsequent reversal to olivine precipitation when the mineralizers were exhausted (Edwards, 1938). In both instances the iddingsite shows a fibrous reaction junction with the olivine which it replaces, but has a sharply defined junction with the rim of olivine that surrounds it, indicating a sudden cessation of reaction and return to the formation of olivine. Since the formation of iddingsite requires oxidizing conditions and the presence of abundant mineralizers, it must be assumed that such conditions were brought about in the laccolith by the relief of pressure that accompanied the doming up of the sedimentary roof.

Similar Occurrences in North-West Tasmania.

Two other laccoliths of analcite-olivine-dolerite occur along the coast of North-West Tasmania. One is the hill known as Mount Cameron West, which lies about 4 miles north of Marrawah, and rises to a height of about 200 feet. This striking hill is a "resumed island" (Edwards, 1941). It has suffered rather more irregular erosion than Circular Head, but in profile it preserves its dome-shape. Erosion at the seaward side has converted that part of the laccolith into a sharp crested ridge. At its eastern end, however, it retains its broad flattish top, which gives place to steep slopes on all sides. Close to sea-level, where it overlies flat-lying (?) Permo-Carboniferous sediments it has been chilled to a fine-grained olivine-basalt. Above this it becomes coarser-grained, but the thickness of the laccolith was not great enough to permit very much differentiation.

The other is the much larger laccolith of Table Cape near Wynyard, which is known to consist of rocks which are microscopically identical with those forming the Circular Head laccolith (Twelvetrees, 1902).

Age Relations.

The age of the Circular Head laccolith cannot be established with any certainty. It is older than the adjacent basalts of the Stanley Peninsula, because these were extruded in a valley that passes below sea-level, so that the valley bottom is at a lower elevation than the base of the laccolith. The laccolith was largely unexposed at the time of the basalt extrusion, because the Permo-Carboniferous beds enclosing it formed the east wall of the pre-basaltic valley. The top of the laccolith may have been uncovered, in view of the hanging valley situated there. The basalts of the Stanley Peninsula are regarded as being of Pliocene age (Nye and Blake, 1938).

At Mount Cameron West there is a similar lack of evidence. A Recent foraminiferal limestone abuts against the laccolith, and there are Miocene limestones in the vicinity, but the relation of the latter to the laccolith is not known. At Table Cape, basalt flows of Pliocene age abut against the laccolith, which had undergone extensive erosion prior to the extrusion of the basalts, and so is considerably older. Stephens (1908) reports that the Lower Miocene beds of Fossil Bluff also abut against the laccolith, but he was unable to say whether or not the contact was an intrusive one. Mr. F. A. Cudmore, however, informs me that this is not so, and that the Miocene beds pass below sea-level before reaching the laccolith. If the laccoliths are shown ultimately to be of pre-Lower Miocene age they may be linked with the pre-Miocene basalts of Marrawah (Nye and Blake, 1938); and it would be tempting to correlate them with the closely comparable crinanite and olivine-analcite-dolerite dykes of the Older Volcanic Series (Oligocene) in South Gippsland, Victoria (Edwards, 1934).

Acknowledgments.

My thanks are due to Dr. A. N. Lewis, who obtained permission for me to climb and examine Circular Head, to Mr. McGaw, of the Van Dieman's Land Company, for permission to visit Mount Cameron West, and to Mr. F. Blake, Acting Government Geologist of Tasmania, for the loan of specimens. The field expenses were defrayed by small research grants from the Australian and New Zealand Association for the Advancement of Science, and the University of Melbourne. The laboratory studies were carried out in the Geology Department of the University of Melbourne, by kind permission of Professor E. W. Skeats.

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[Proc. Roy. Soc. Victoria, **53** (N.S.), Pt. II., 1941.]

Art. XV.—*Note of the Occurrence of Fossiliferous Devonian Tuffs in the Dandenong Ranges.*

By EDWIN SHERBON HILLS, Ph.D., D.Sc.

[Read 12th December, 1940; issued separately 26th July, 1941.]

Introduction.

In December, 1939, while on a visit to Mt. Dandenong, I noted with interest the occurrence of fine-grained bedded tuffs, closely resembling certain of the tuffaceous Upper Devonian fish beds at Taggerty, inter-stratified with the dacites on the western flanks of the mountain. Although at the time no fossils were obtained, the probability that these tuffs would prove fossiliferous appeared to be strong, and on a subsequent occasion the excellent sections on the new road from Montrose to Kalorama were examined. Tuffaceous beds were then discovered at two localities, one of which yielded fragmentary carbonized plant remains. These fossils, although unfortunately indeterminate, are of considerable significance in that they indicate with certainty the stratification planes in the beds in which they occur, thus permitting the measurement of dip and strike. The presence of the tuffs also enables the upper and lower surfaces of the adjacent lava flows to be determined, giving precise limits to certain of the flows, which previously it had not been possible to fix.

In view of the significance of the occurrence of the tuffs, a rapid reconnaissance of the western flanks of the main Dandenong Range was made, and further discoveries were made at the localities indicated on the map (fig. 1). Plant remains of a type similar to those on the Kalorama road were obtained from two more places, one on the old road from Montrose to Kalorama, and the other at the Glenfern Quarry at Ferntree Gully. The tuffs were thus shown to constitute an important horizon among the lavas, extending over a distance of seven miles along their strike. They therefore afford an important clue to the structure of the Dandenong Range, the significance of which will be discussed below. No attempt, however, has been made at a detailed survey of the district, as a comprehensive study of this and neighbouring areas is being undertaken by another investigator.

The Structure of Mt. Dandenong.

As has been shown by Morris Morris (1914), the Dandenong Ranges and the adjacent country on the north and west are composed chiefly of lava flows, ranging from toscanites at the base of the succession to hypersthene dacite at the top. The lavas are believed to be Upper Devonian in age, for reasons which

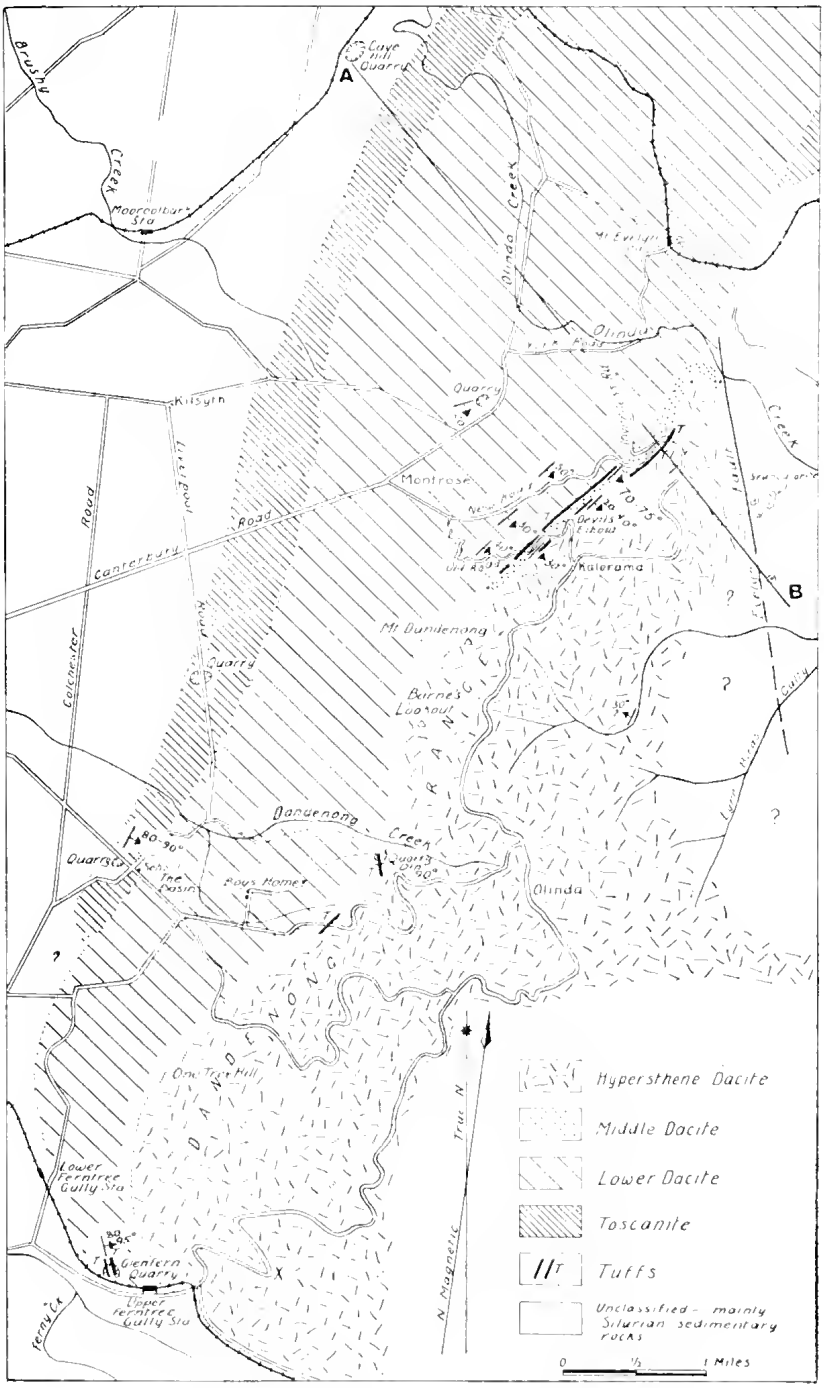

FIG. 1.—Sketch Geological Map of the Dandenong Ranges. Boundaries mainly after Morris Morris (1914), generalized to reveal trend-lines.

have been fully set out in previous publications (Hills, 1931, 1935). Although the newly discovered plant remains have no strict bearing on the age of the lavas, owing to their indeterminate nature, nevertheless they bear a certain superficial resemblance to the plant remains discovered by Hauser in the south Blue Range at Mansfield, these being associated with Upper Devonian fishes (Cookson, 1937; Hills, 1936).

The fossiliferous tuffs on the new road from Montrose to Kalorama are immediately overlain by fresh dacite which exhibits well-marked flow structure. The flow planes, and also the major joints in this dacite are parallel with the stratification planes in the fossiliferous tuffs, and, therefore, must both have been originally horizontal. In the dacite under the tuffs (see detailed sketch map, fig. 2) flow planes are well-marked in places, though elsewhere they are not discernible with certainty. They again indicate the bedding in the lava, but in this rock the major joints have no readily recognizable relationship with the flow planes, usually cutting across them at various angles. It is clear from the sections along this road, however, that for purposes of mapping, the flow planes afford reliable guides to the bedding in the lavas, and that their dip and strike are structurally significant.

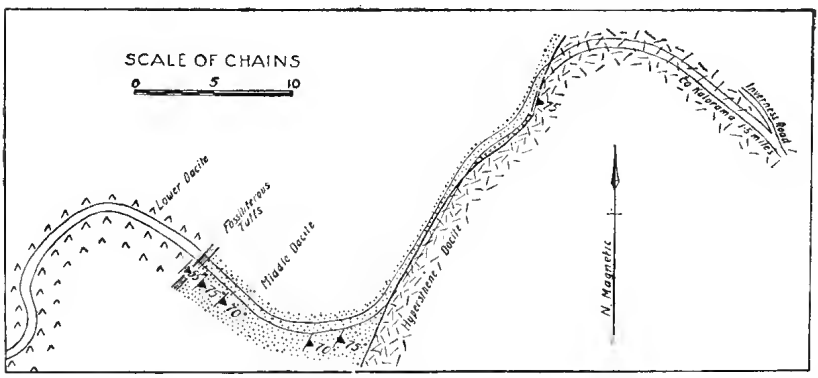

FIG. 2.—Sketch map showing the position of the fossiliferous tuffs on the new road from Montrose to Kalorama, in relation to the adjacent lavas. Dips and strikes of bedding and flow planes are indicated.

Morris Morris was the first to subdivide the lavas of the district into distinct petrological types, but on Mt. Dandenong itself he was unable to indicate any actual boundaries exposed in natural sections. He showed the lavas as essentially horizontal sheets in his cross sections, and there has been no subsequent suggestion that this interpretation might not be correct. It was somewhat surprising to find, therefore, that in the exposures on the new road the tuffs and lavas are dipping at high angles of from 30 degrees to 75 degrees in a south-easterly direction (see figs. 1 and 2). High dips prevail at and above the fossiliferous

tuffs, but on the lower slopes of the mountain there is a gradual decrease to 30 degrees. In two small quarries about 200 yards above Long View House on the new road a characteristic bed of agglomerate, interstratified with the dacites, dips at 30 degrees in conformity with the flow planes in the lavas, thus justifying the use that has been made of the flow planes in mapping.

Owing to Morris' inability to indicate precise boundaries for the middle dacite, there has been in the past some difficulty in the identification of this flow. The upper (hypersthene) dacite is usually readily distinguishable from the lower lavas, chiefly by its characteristic fine texture, and its base can be accurately located on the new road. At its junction with the underlying flow, which is somewhat undulating but dips on the average at 78 degrees to 80 degrees, there occur fine-grained tuffs which are peculiar in that they not only mantle the surface of the lower flow but also extend into it, isolating lenticular masses from the massive rock beneath, and penetrating along cracks. It is suggested that at the time the tuffs were laid down, the surface of the flow on which they were deposited was cracked and covered with boulders. The tuffs entered the cracks, surrounded the boulders, and then, when the hypersthene dacite was extruded and also during subsequent earth movements, shearing occurred in the soft tuffs, the boulders being rolled along and incorporated in them.

The base of this underlying flow immediately overlies the fossiliferous tuffs lower down the road, there being no visible break within the lava between these limits. This flow, then, should correspond with Morris' middle dacite. His mapping agrees with this interpretation, and the petrological characters of the flow correspond closely with his description of the middle dacite. Commencing at the base with a markedly banded type containing coarse and fine layers, the rocks passes up into a facies characterized by numerous large plagioclase phenocrysts with subordinate quartz and biotite, while at the top the phenocrysts are rather smaller, quartz increasing in amount. The nature of the groundmass, shimmering with small flakes of pale-brown biotite, was also commented on by Morris. There can be no doubt, therefore, that this flow, between the precise limits indicated, constitutes the middle dacite as defined by him.

Conforming with this interpretation, the petrological characters of the lavas immediately below the fossiliferous tuffs agree with Morris' description of the lower dacite. This series contains garnet in fair amount, and possesses a granular quartzo-felspathic groundmass with phenocrysts of quartz, plagioclase, and biotite. It is notably fragmental in places, the occurrence of bedded agglomerate at the small quarries referred to above indicating that it consists of more than one flow. The base of this series was accurately located by Morris at several points, and its top is now shown to be at the fossiliferous tuffs on the new road.

On the basis of the reconnaissance survey that has been made, a provisional sketch section showing the structure between Mt. Dandenong and Lilydale may be drawn (fig. 3). While the areal mapping of Morris and observations of flow planes in the lavas indicate the structure of the country to the west of the base of the hypersthene dacite with some degree of accuracy, the interpretation of the eastern part of the section is not easy. Reliable measurements on flow planes in the hypersthene dacite are difficult to obtain, but there is a suggestion in the field, which is to some extent borne out by physiographic evidence, that the dips decrease rapidly towards the east, as they certainly do to the north of York Road. Morris' mapping (1914, Pl. XXX.), shows clearly that in the Lilydale and Mt. Evelyn districts, the general structure of the lavas is that of a broadly open syncline, flanked by the toscanites on the west, north and east. South from Evelyn, however, the eastern boundary is shown by him as the Evelyn Fault, and as will be clear from fig. 1, there can be little doubt that the country to the west of this fault has been downthrown, the steeply-dipping lavas on the northern flanks of Mt. Dandenong being truncated along the line of the fault. The southerly extension of the Evelyn Fault, and of the synclinal structure referred to in the north, is however quite uncertain at present.

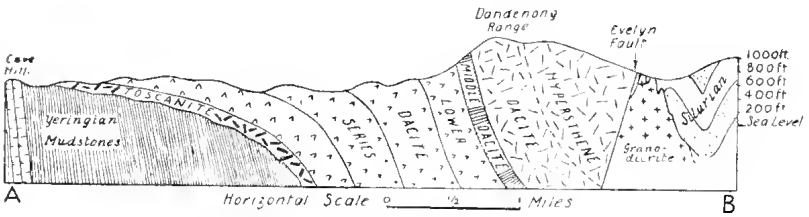

Fig. 3.—Geological section along the line A-B on Fig. 1.

The thickness of the various flows in this district is, as may be seen by comparing fig. 3 with Morris' cross sections, much greater than was formerly thought. The middle dacite is approximately 700 feet thick on Mt. Dandenong, and the lower dacite series of the order of 4,000 feet, the precise values not being determinable without further detailed mapping of boundaries and flow planes.

Structure of the Southern Area.

In traversing south from the new Montrose-Kalorama road, the dips are at first found to decrease somewhat from the high angles of 70 degrees to 75 degrees observed further north, and angles of from 30 degrees to 40 degrees are common. In the disused quarry on the road to "Doongala" near the head of Dandenong Creek, however, pyritized tuffs occur dipping at approximately 90 degrees, although about three-quarters of a mile further

south, on the road from the Basin to Olinda, the dip is apparently much lower, reliable readings on bedding planes not being obtainable. In the Glenfern Quarry at Upper Ferntree Gully, excellent exposures are available, and the occurrence of fossils again removes all doubt as to the attitude of the bedding planes. The fossiliferous tuffs strike at N. 20 W., and dip at 80 degrees in a westerly direction. In all other parts of the quarry, however, flow planes and bedding planes dip at 70 degrees to 80 degrees in an easterly direction, so that it would appear that the plant beds are locally overturned. On the eastern side of the quarry, fine-grained bedded tuffs form massive beds that have been indurated and pyritized, pyritization of the tuffs being also noted at the two localities near Dandenong Creek, above referred to. There are at least two distinct horizons of tuffs in the quarry, and it is, therefore, obvious that several lava flows are present. There is a wide range in the texture of the flows, from dense blue-black types with scattered phenocrysts of quartz, plagioclase, and garnet, to coarsely crystalline saccharoidal varieties. All, however, show a close resemblance to the lower dacite series at the northern end of the range, and the occurrence of interbedded tuffs at the Glenfern Quarry substantiates the conclusion above arrived at that the "lower dacite" is a composite series consisting of interbedded lavas, tuffs, and agglomerates.

In the southern area, the toscanites at the base of the lava succession, as well as the overlying dacites, are steeply dipping. This may be seen in the small quarry near the Basin, where the toscanite is nearly vertical. High dips are thus an essential feature of the main Dandenong Range in a zone extending from Ferntree Gully to Mt. Dandenong, and this discovery affords an adequate structural explanation of the very steep slopes that are characteristic of the western flank of the Dandenong Range. The range is indeed an asymmetrical hogback, with a number of high points such as Mt. Dandenong, Barnes' Lookout, and One Tree Hill, all in hypersthene dacite, on its summit. On the east, however, the hypersthene dacites form a maturely dissected plateau only slightly lower in general elevation than the summit of the main range. This suggests, as above indicated, that the dips may flatten in this direction. Reliable measurements on flow planes could not, however, be obtained in the hypersthene dacite in this district.

Conclusion.

The present investigation has implications concerning several controversial questions of local geology. Firstly, the hypothetical Dandenong Fault, postulated with reservation by Jutson (1911) as bounding the Croydon Lowlands on the east is, as has been previously argued (Hills, 1934), a purely erosional feature. Actually, as was previously concluded on purely physiographic grounds (Hills, 1934, p. 160; 1940, p. 253), the lavas of the Dandenong Range owe their preservation to having been

originally depressed within the crust by folding, possibly aided by ancient faulting, and their present topographic elevation is due to their resistance to erosion. In this regard, the views expressed by Morris Morris (1914, p. 359) were essentially correct, although he regarded the depression of the lavas as being due to their downfaulting between a hypothetical Montrose Fault on the west and the Evelyn Fault on the east. Morris postulated the Montrose Fault because of the rectilinear nature of the junction between the toscanites and the lower dacites. This junction, it will now be clear, is rectilinear because of the high dips in the lavas, and there is no necessity to postulate the existence of a fault in the position shown by him. The structure, insofar as it can be interpreted at present, is rather that of a great monoclinal fold, the axis of which runs obliquely across the lavas of the ranges, in a S.W.–N.E. direction. This axis, in the north, is itself truncated by the Evelyn Fault, trending from east of south to west of north. Along and adjacent to this fault, minor intrusions of granitoid rocks have made their way. In the Ferntree Gully district, however, where the western edge of the lava succession dips at approximately 90 degrees, it may well be that the monocline has passed laterally into a fault, which now separates the Silurian rocks on the west from the Upper Devonian lavas on the east.

In conclusion it may be remarked that the final elucidation of the structure of the Dandenong Ranges, which must await further detailed research, may be expected to have a notable bearing on the Siluro-Devonian tectonics of Victoria, since a Lower or perhaps even Middle Devonian age has recently been indicated for the Lilydale limestone by Dr. Dorothy Hill (1939).

The assistance of Dr. A. B. Edwards in discussions during the preparation of this note is gratefully acknowledged.

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[Proc. Roy. Soc. Victoria, **53** (N.S.), Pt. II., 1941.]

Art. XVI.—*Studies in Australian Tertiary Mollusca, Part II.*

By F. A. SINGLETON, D.Sc.

[Read 12th December, 1940; issued separately 26th July, 1941.]

In the nine years since the communication of Part I. of this series, much new material has been accumulated, part of which is dealt with in the present paper, again confined to Pelecypoda, wherein the following new names are proposed and the new species figured:—

Nucula (*Ennucula*) *gricei*, sp. nov.
Nuculana (*Scaeoleda*) *killara*, sp. nov.
Limopsis werrikooensis, sp. nov.
Glycymeris (*Veletuceta*) *pseudaustralis*, sp. nov.
Ostrea sinuata glenelgensis, subsp. nov.
Notochlamys antecedens, nom. nov.
Aulacomya suberosa, sp. nov.

I am again under obligations to the Director, Mr. D. J. Mahony, and the Palaeontologist, Mr. R. A. Keble, of the National Museum, Melbourne, for continued access to the collections housed therein, and for allowing me to describe new species from them. To the late Miss J. Wilson-Smith, Mr. J. S. Mann, and Mr. G. Baker, I am indebted in respect to the illustrations.

Class PELECYPODA.

Family NUCULIDAE.

Genus **Nucula** Lamarck, 1799.

Subgenus **Ennucula** Iredale, 1931.

(*Vide* "Studies," Part I., p. 290, 1932.)

This name, proposed as a full genus by Iredale, but regarded only as a section of *Nucula* by the writer (1932, p. 292), may perhaps be accorded subgeneric rank, a course adopted by Schenck (1934, p. 46). It may be noted that in Schenck's revision he has figured from the Arafura Sea (1934, pl. 3, fig. 4) under the name of *Nucula obliqua* Lamarck (the type species of *Ennucula* Iredale) a Recent shell, clearly *Nucula superba* Hedley (1902, p. 292), which occurs in Northern Australia, whereas *N.* (*E.*) *obliqua* is confined to S.E. Australian seas.

Nucula (Ennucula) gricei, sp. nov.

(Pl. XX., figs. 1*a*, *b*.)

"*Nucula tenisoni* Pritchard," Singleton, 1932, p. 292, pl. xxiv., figs. 5*a*, *b*. Not *Nucula tenisoni* Pritchard, Proc. Roy. Soc. Vic., n.s., viii., p. 128.

Holotype.—Shell thin, subovate, very inequilateral, posteriorly somewhat produced, moderately depressed; umbonal angle 140 degrees, anterior margin evenly rounded, posterior margin short, subtruncate; surface mostly smooth, with weak concentric folds towards ventral margin; hinge, slender, gently arcuate, with nineteen teeth, of which three are rudimentary, in anterior and six teeth in posterior series, separated by an oblique anteriorly directed resilifer; interior nacreous, shining, inner ventral margin smooth. Length 14.3; height 10; thickness of valve 3.6 mm.

Type Locality.—Grice's Creek, between Frankston and Mornington, Victoria. Balcombian (Middle Miocene ?).

Type Material.—Holotype (Pl. XX., figs. 1*a*, *b*), right valve, coll. and pres. F. A. Singleton, Melbourne University Geology Department Palaeont. Coll., Reg. No. 1311.

The differences from *N. tenisoni* already noted (1932, p. 292), together with the apparent restriction of the present species to the Balcombian stage, to which the writer (1941, p. 73) would now refer the Barwonian localities at which it is found, make advisable its separation as a new species.

Family NUCULANIDAE.

Genus **Nuculana** Link, 1807.

Nuculana Link, Beschr. Samml. Rostock, iii., p. 155, 1807.

Type (by monotypy): *Arca rostrata* Chemnitz = *Mya pernula* Müller. Recent, Northern Europe.

Subgenus **Scaeoleda** Iredale, 1929.

Scaeoleda Iredale, Rec. Aust. Mus., xvii. (4), pp. 158, 187, 1929.

Type (by original designation): *Nucula crassa* Hinds. Recent, S. Tasmania.

Nuculana (Scaeoleda) killara, sp. nov.
(Pl. XX., fig. 2.)

Holotype.—Shell small, elongate ovate, moderately depressed, posterior slope flattened, bounded by a marked posterior keel; anterior end rounded, posterior end bluntly rostrate, ventral margin evenly rounded, post-dorsal margin nearly straight; umbo low, slightly anterior. Surface finely concentrically striate, sculpture stronger anteriorly and towards ventral margin. Hinge teeth chevron-shaped, about 15 anterior and 13 posterior, separated by a triangular pit. Length 10, height 5.5, thickness of valve 2 mm.

Type Locality.—Glenelg River at "Roscoe's," Parish of Killara, Western Victoria. Werrikooian (Uppermost Pliocene).

Type Material.—Holotype (Pl. XX., fig. 2), left valve, coll. and pres. F. A. Singleton, Melb. Univ. Geol. Dept., Reg. No. 1673.

This nearly smooth species distantly recalls the Kalimnan (Lower Pliocene) *Nuculana woodsii* (Tate) (1886, p. 133, pl. 9, fig. 8), which is more inflated, elongate and rostrate.

Dennant and Kitson (1903, p. 146) have recorded from "Limestone Creek," which refers to the same general locality, a worn juvenile of this species as *Leda inconspicua* Adams.

Family LIMOPSIDAE.

Genus **Limopsis** Sassi, 1827.

(*Vide* "Studies," Part I., p. 296, 1932.)

LIMOPSIS WERRIKOOENSIS, sp. nov.

(Pl. XX., figs. 3*a*, *b*.)

Holotype.—Shell ovate, subequilateral, narrowed at hinge, weakly convex; umbo minute, prominent; surface with about 40 narrow radiating ribs, interspaces occupied by fine concentric growth lines, weaker than the radial ornament. Hinge-line narrow, arcuate, bearing 9 anterior and 13 posterior hinge-teeth, slightly curved; ligament pit large, broadly triangular. Interior finely radially striate, inner margin smooth, planate. Length 18, height 18, thickness of valve 4 mm.

Type Locality.—"Limestone Creek" = Glenelg River, Western Victoria. Werrikooian (Uppermost Pliocene).

Type Material.—Holotype (Pl. XX., fig. 3*a*, *b*), left valve, ex Dennant Coll., National Museum, Melbourne, Reg. No. 14090.

This differs from its living relative, *L. tenisoni* T. Woods, under which name Dennant and Kitson recorded it, in its less oblique outline and more sloping shoulders on either side of a more acute umbo.

Family GLYCYMERIDAE.

Genus **Glycymeris** Da Costa, 1778.

(*Vide* "Studies," Part I., p. 294, 1932.)

Subgenus **Veletuceta** Iredale, 1931.

Veletuceta Iredale, Rec. Aust. Mus., xviii. (4), pp. 203, 231, 1931.

Type (by original designation): *Glycymeris flammeus* Reeve. Recent, S.E. Australia.

GLYCYMERIS (VELETUCETA) PSEUDAUSTRALIS, sp. nov.

(Pl. XX., figs. 4, 5.)

Holotype.—Right valve of an ephebic example. Subcircular, nearly equilateral, depressed convex; umbo minute, prominent, opisthogyrate. Surface almost smooth, faintly marked by numerous fine radii, about 8 in 5 mm. at the centre of the disc, becoming obsolete posteriorly, and by extremely fine striae; the whole crossed by fine concentric lines and numerous but indistinct growth stages. Hinge-line arcuate; hinge-teeth slender, 10 anterior and 9 posterior, the latter slightly uncinate; ligamental area high, with 5 oblique striae in a space of 2 mm.; inner ventral margin strongly crenate. Length 34, height 31, thickness of valve 9 mm.

Paratype.—A larger right valve which in the gerontic stage is higher than long and somewhat truncate post-dorsally. The surface bears about 40 flat ribs, becoming obsolete anteriorly and posteriorly, with linear interspaces. Length 44, height 45, thickness of valve 13 mm.

Type Locality.—Glenelg River at "Roscoe's," Parish of Killara, Western Victoria. Paratype from Caldwell's Cliff, Glenelg River, Parish of Werrikoo, Western Victoria. Werrikooian (Uppermost Pliocene).

Type Material.—Holotype (Pl. XX., fig. 4), Melb. Univ. Geol. Dept. Reg. No. 1674 and paratype (Pl. XX., fig. 5), Melb. Univ. Geol. Dept., Reg. No. 1675, both coll. and pres. F. A. Singleton.

This species recalls the Recent *G. flammea* Reeve = *G. australis* (Q. and G.), which is stouter and more transversely ovate. Its minute but prominent umbo and smoother more depressed shell distinguish it from the Tertiary *G. cainozoica* (T. Woods) and *G. halli* Pritchard.

The imperfect holotype of *G. australis* var. *gigantea* Chapman from the supposed Werrikooian of Kangaroo I., S.A., figured by Chapman and Singleton (1925, p. 47, pl. 3, fig. 32) is not, in my opinion, a glycymerid, but is a lucinid, closely comparable with *Lucina philippinarum* Hanley.

Family OSTREIDAE.

Genus **Ostrea** Linné, 1758.

Ostrea Linné, Syst. Nat., ed. 10, p. 696, 1758.

Type (by subsequent designation, Children, Quart. Journ. Sci., Lit., Arts, xv., p. 44, 1823): *Ostrea edulis* Linné. Recent, Europe.

Ostrea sinuata glenelgensis, subsp. nov.

(Pl. XX., fig. 6.)

Holotype.—Shell broadly oblong, moderately large, solid, somewhat produced anteriorly to umbo. Lower valve moderately convex, with irregular concentric lamellae and obsolescent radial ribs; upper valve flattened, concentrically lamellate. Muscle scar large, ovate, excavated above, slightly posterior, weakly impressed. Length 93, height 100, thickness of paired valves 35 mm.

Type Locality.—Glenelg River above Limestone Creek, Allot. 16A, Parish of Werrikoo, Western Victoria. Werrikooian (Uppermost Pliocene).

Type Material.—Syntypes (paired valves), coll. and pres. F. A. Singleton, Melb. Univ. Geol. Dept., Reg. Nos. 1676 (left valve, Pl. XX., fig. 6), and 1677 (right valve).

Tate (1886, p. 110) has recorded this fossil as *O. angasi* Sow. (= *sinuata* Lam.) from Limestone Creek and Ascot Heath, and Dennant and Kitson (1903, p. 145) so list it. In the Glenelg Cliffs at Caldwell's Cliff, Ascot Heath and Dartmoor, it forms oyster beds which, from the presence of *Pecten (Notovola) meridionalis* (Tate), I have recently placed on a slightly higher horizon, probably Lower Pleistocene (1941, pp. 47, 48).

In so variable a genus, it is with some hesitation that the fossils are separated from the common mud oyster of S.E. Australia, to which they are evidently ancestral, but they differ in the greater width at the hinge, the dorsal margin being straight or obtusely angled at the umbo, and the radial ribbing practically obsolete. Victorian *O. sinuata*, s. str., is usually more shouldered at the umbo and the radial ribbing of the lower valve is well developed.

A more distant relative is the Lower Pliocene *O. arenicola* Tate, which bears fewer but stronger costae.

Family PECTINIDAE.

Genus **Notochlamys** Cotton, 1930.

Notochlamys Cotton, Rec. S. Aust. Mus., iv. (2), p. 233, 1930.

Type (by original designation): *Chlamys anguineus* Finlay = *Pecten undulatus* Sowerby. Recent, Southern Australia.

NOTOCHLAMYS ANTECEDENS, nom. nov.

Pecten praecursor Chapman, 1912, p. 36, pl. 5, figs. 1-3. Not *Pecten (Amusium) precursor* Dall, Trans. Wagner Free Inst. Sci., iii. (4), p. 755, 1898.

Dall's and Chapman's specific names are homonyms, since they are pronounced identically and the difference in spelling is insufficient, according to the International Rules of Zoological Nomenclature, to validate the later name, for which a substitute is therefore offered.

Type Locality.—Spring Creek, Torquay, Victoria. Janjukian (Lower Miocene). Paratypes from Waurn Ponds (Janjukian) and Curlewis (Balcombian: by Chapman called Barwonian), both near Geelong, Victoria.

Type Material.—Holotype, left valve, ex Dennant Coll., Nat. Mus., Melb., Reg. No. 12590. Paratypes, ex Coll. Geol. Surv. Victoria, Nat. Mus. Reg. Nos. 12591 (Waurn Ponds) and 12592 (Curlewis).

Family MYTILIDAE.

Genus **Aulacomya** Mörch, 1853.

Mytilus (Aulacomya) Mörch, Cat. Conch. Yoldi, ii., p. 53, 1853.

Type (by subsequent designation, Jhering, Proc. Malac. Soc. Lond., iv. (2), p. 87, 1900): *Mytilus magellanicus* Lamarck (as of Chemnitz). Recent, South America.

AULACOMYA SUBEROSA, sp. nov.

(Pl. XX., fig. 7.)

"*Mytilus magellanicus* Lamarck." Dennant, 1887, p. 236. Dennant and Kitson, 1903, p. 146. Not *Mytilus magellanicus* Chemnitz, Conch. Cab., viii., p. 162, pl. 83, figs. 742-3. Lamarck, Anim. s. Vert., vi., p. 119, 1819.

"*Mytilus menkeanus* Philippi." Dennant, 1887, p. 236. Not *Mytilus menkeanus* Philippi, Zeit. f. Malak., iv., p. 118, 1847 (= *M. crosus* Lamarck, 1819).

Holotype.—Shell elongately subtrigonal; inflated anteriorly, compressed posteriorly; umbo acute, slightly curved; dorsal margin straight, passing evenly into the regularly rounded posterior margin; anterior margin very long, straight. Area anterior to the elevated umbonal ridge very steep, with fine radial riblets, about $1\frac{1}{2}$ per mm. Sculpture of coarse, wavy radial riblets, narrower than the interspaces, increasing by occasional bifurcation or intercalation, about 20 at the posterior margin, where they are about 2 mm. apart; on the precipitous area anterior to the strong umbonal ridge they are finer and average $1\frac{1}{2}$ per mm.; growth stages prominent. Margins very worn, but apparently smooth, with ligamental groove dorsally. Greatest length 61, greatest width at right angles 20, thickness 9 mm.

Type Locality.—"Limestone Creek" = Glenelg River, Western Victoria. Werrikooian (Uppermost Pliocene).

Type Material.—Holotype (Pl. XX., fig. 7), ex Dennant Coll., Nat. Mus., Melb., Reg. No. 14091.

The straight (rarely concave) anterior margin, acute beaks and absence of a post-dorsal bulge at once distinguish it from *A. erosa* Lk., now living in this region. There is a closer resemblance to the Neozelanic *A. maoriana* (Iredale), in which the beaks are more curved and the ribbing slightly finer. Kerguelen shells labelled as *Mytilus magellanicus* differ again in outline and have coarser ribbing than either of the preceding.

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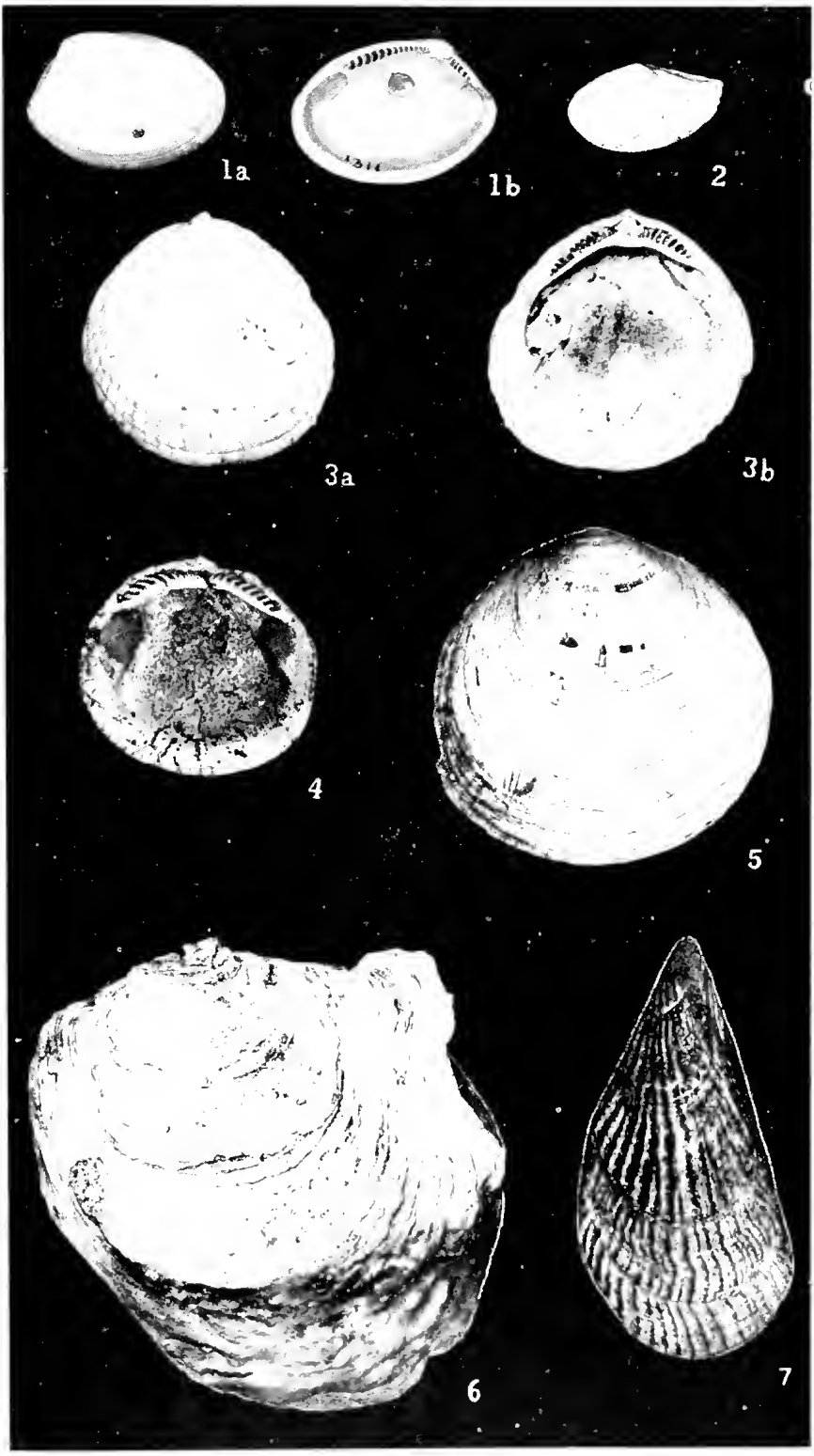
Explanation of Plate.

Plate XX.

Fig. 1a, b.—*Nucula (Ennucula) gricei*, sp. nov. Holotype. × 2.
Fig. 2.—*Nuculana (Scaeoleda) killara*, sp. nov. Holotype. × 2.
Fig. 3a, b.—*Limopsis werrikooensis*, sp. nov. Holotype. × 2.
Fig. 4.—*Glycymeris (Veletuceta) pseudaustralis*, sp. nov. Holotype, nat. size.
Fig. 5.—*Glycymeris (Veletuceta) pseudaustralis*, sp. nov. Paratype, nat. size.
Fig. 6.—*Ostrea sinuata glenelgensis*, subsp. nov. Syntype, lower valve, × $\frac{2}{3}$.
Fig. 7.—*Aulacomya subcrosa*, sp. nov. Holotype, nat size.



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MacCallum, Prof. Peter, M.C., M.A., M.Sc., M.B., Ch.B., D.P.H., University, Carlton, N.3 1925
Miller, E. Studley, 396 Flinders-lane, Melbourne, C.1 1921
Miller, Leo F., "Moonga," Power-avenue, Malvern, S.E.4 .. 1920
Mackinnon, J. C., Melbourne Club 1938
Morrison, P. Crosbie, M.Sc., 44-74 Flinders-street, C.1 1938
Nicholas, Geo. R., 48 Lansell-road, Toorak, S.E.2 1934
Orr, Dr. R. Graeme, M.A., B.Ch., 11 Maple-grove, Toorak, S.E.2 .. 1935
Orr, Dr. W. F., 8 Collins-street, Melbourne, C.1 1932
Parr, W. J., 17 Bokhara-road, Caulfield, S.E.8 1927
Patton, R. T., D.Sc., M.F., Hartley-avenue, Caulfield, E.8 1922
Penfold, Dr. W. J., M.B., 53 Prospect Hill-road, Camberwell, E.6 .. 1923
Piesse, E. L., 43 Sackville-street, Kew, E.4 1921
Priestley, R. E., M.A., D.Sc., University, Birmingham 1935
Quayle, E. T., B.A., 27 Collins-street, Essendon, W.5 1920
Rae, F. J., B.A., B.Sc., B.Ag.Sc., Botanic Gardens, South Yarra, S.E.1 1927
Reid, J. S., 498 Punt-road, South Yarra, S.E.1 1924
Richardson, A. E. V., M.A., D.Sc., C.M.G., Council for Scientific and Industrial Research, 314 Albert-street, East Melbourne, C.2 1938
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Rivett, Sir David, M.A., D.Sc., Council for Scientific and Industrial Research, 314 Albert-street, East Melbourne, C.2 1911
Rogers, J. Stanley, B.A., M.Sc., University, Carlton, N.3 1924

Sewell, Dr. S. V., 12 Collins-street, C.1 1936
Singleton, F. A., D.Sc., University, Carlton, N.3 1917
Stillwell, F. L., D.Sc., 44 Elphin-grove, Hawthorn, E.2 1910
Summers, Prof. H. S., D.Sc., University, Carlton, N.3 1902
Thomas, Dr. D. J., M.D., 81 Collins-street, Melbourne, C.1 .. 1924
Tiegs, O. W., D.Sc., University, Carlton, N.3 1925
Turner, Professor J. S., M.A., Ph.D., University, Carlton, N.3 .. 1938
Vail, Lieut.-Col. L. E., 485 Bourke-street, Melbourne, C.1 .. 1939
Wadham, Prof. S. M., M.A., Agr. Dip., University, Carlton, N.3 .. 1932
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White, Dr. A. E. Rowden, 14 Parliament-place, Melbourne, C.2 .. 1938
Withers, R. B., M.Sc., Dip. Ed., University High School, Parkville, N.2 1926
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Young, Prof. W. J., D.Sc., University, Carlton, N.3 1923

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Blackburn, Maurice, M.Sc., Fisheries Section, C.S.I.R., Cronulla, N.S.W. 1936
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Cox, H. M. S., Wombat Park, Daylesford 1931
Crawford, W., Gisborne, Vic. 1920
Glaessner, M. F., Ph.D., c/o Australasian Petroleum Co., Port Moresby, Papua 1939
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Broadhurst, E., M.Sc., 457 St. Kilda-road, Melbourne, S.C.2 .. 1930
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Chapman, W. D., Major, M.C.E., "Hellas," Stawell-street, Kew, E.4. 1927
Chapple, Rev. E. H., The Manse, Warrigal-road, Oakleigh, S.E.12 .. 1919
Clark, J., F.L.S., National Museum, Melbourne, C.1 1929
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Collins, A. C., 3 Lawrence-street, Newtown, Geelong 1928
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Coulson, A. L., D.Sc., D.I.C., F.G.S., Geological Survey of India, 27 Chowringhee, Calcutta 1919
Cowen, Miss Margot E. H., B.Agr.Sc., 2 Leaburn-avenue, S.E.7 .. 1936
Crespin, Miss I., B.A., Department of the Interior, Canberra, F.C.T. 1919
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Head, W. C. E., North-street, Nathalia 1931
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Holland, R. A., 526 Toorak-road, Toorak, S.E.2 1931
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Holmes, W. M., M.A., B.Sc., 1 Balmoral-avenue, Kew, E.4 .. 1913
Honman, C. S., B.M.E., Melbourne Technical College, 134 Latrobe-street, C.1 1934
Hutchinson, R. C., B.Sc., Dept. of Agriculture, Rabaul 1939
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Jacobson, R., M.Sc., Woodbine-grove, Chelsea 1937
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McCance, D., M.Sc., 144 Gatehouse-street, Parkville, N.2 1931
MacDonald, B. E., "The Heights," 127 Banksia-street, Heidelberg, N.22 1920
McIver, Miss Euphemia, M.Sc., Higher Elementary School, Rochester 1936
McLennan, Assoc. Prof. Ethel, D.Sc., University, Carlton, N.3 .. 1915
Macpherson, Miss J. Hope, National Museum, Melbourne . 1940
Manning, N., 55 Carroll-crescent, Gardiner, S.E.6 1940
Melhuish, T. D'A., M.Sc., Mt. Frome Lime Co., Burrow-road, St. Peters, Sydney 1919
Morris, P. F., National Herbarium, South Yarra, S.E.1 1922
Mushin, Mrs. Rose, 150 Garton-street, North Carlton, N.4 1940
Newman, B. W., B.Sc., Meteorological Bureau, Sydney 1927
Nye, E. E., College of Pharmacy, 360 Swanston-street, Melbourne, C.1 1933
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Osborne, N., c/o Australasian Petroleum Co., Port Moresby .. 1930
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Pretty, R. B., M.Sc., Technical School, Wonthaggi, Vic. 1922
Raff, Miss J. W., M.Sc., F.R.E.S., University, Carlton, N.3 .. 1910
Rayment, Tarlton, Bath-street, Sandringham, S.8 1929
Richardson, Sidney C., 2 Geelong-road, Footscray, W.11 1923
Rosenthal, Newman H., B.A., B.Sc., 10 Oulton-street, Caulfield, S.E.7 1921
Rothberg, M., B.Agr.Sc., Graduate School, Univ. of Minnesota, St. Paul, Minnesota, U.S.A. 1937
Sayce, E. L., B.Sc., A.Inst.P., Research Laboratories, Maribyrnong, W.3 1924
Scott, T. R., M.Sc., B.Ed., 27 Currajong-avenue, Camberwell, E.6 .. 1934
Shaw, Dr. C. Gordon, 57 Clendon-road, Toorak, S.E.2 1931

Sherrard, Mrs. H. M., M.Sc., 43 Robertson-road, Centennial Park, N.S.W. 1918

Stach, L. W., M.Sc., c/o Australasian Petroleum Co., Port Moresby, Papua 1932

Sutherland, Miss Jean L., M.Sc., Presbyterian Girls School, Glen Osmond, Adelaide, S.A. 1934

Thomas, L. A., B.Sc., c/o Council for Scientific and Industrial Research, Stanthorpe, Queensland 1930

Traill, J. C., B.A., B.C.E., 630 St. Kilda-road, Melbourne, S.C.3 .. 1903

Trüdinger, W., 27 Gerald-street, Murrumbeena, S.E.9 1918

Tubb, J. A., M.Sc., Fisheries Section, C.S.I.R., Cronulla, N.S.W. .. 1936

Vasey, A. J., B.Agr.Sc., "Westaways," Werribee 1937

Vasey, G. H., B.C.E., University, Carlton, N.3 1936

Wilcock, A. A., B.Sc., B.Ed., 4 Melville-avenue, Frankston .. 1934

Wilson, F. E., F.E.S., 23 Ferncroft-avenue, E. Malvern, S.E.5 .. 1921

Wilson, Major H. W., O.B.E., M.C., C. de G., M.Sc., 630 Inkerman-road, Caulfield, S.E.7 1923

Wood, E. J. F., M.Sc., B.A., Fisheries Section, C.S.I.R., Cronulla, N.S.W. 1935

Wood, Assoc. Prof. G. L., M.A., Litt. D., University, Carlton, N.3 .. 1933

Woodburn, Mrs. Fenton, 21 Bayview-crescent, Black Rock, S.9 .. 1930

Wunderly, J., D.D.Sc. (Melb.), 2 Collins-street, Melbourne, C.1 .. 1937

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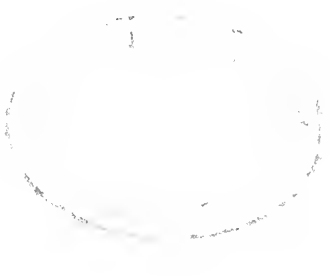
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